NORSK GEOLOGISK TIDSSKRIFT

UTGITT AV

NORSK GEOLOGISK FORENING

MED STATSBIDRAG SAMT MED BIDRAG FRA
NORGES ALMENVITENSKAPELIGE FORSKNINGSRÅD

BIND 30

OSLO 1952
A. W. BRØGGERS BOKTRYKKERI A/S

INNHOLD

Side
Adamson, Olge J. and Henrich Neumann: Tungsten in Southern Norway 135
Broch, Olaf Anton: Narrative of a Rock Fragment 183
— Note on a Fault Breccia in Hallingdal, Norway, together with Some General Remarks on the Fracturing of the Earth's Crust 185
Bugge, Carl: Statsgeolog Steinar Foslie. Minnetale 190
Falck-Muus, Rolf: Steinar Foslies yrke i trykk og skrift 195
Gjelsvik, Tore: Metamorphosed Dolerites in the Gneiss Area of Sunnmøre on the West Coast of Southern Norway 33
Henningsmoen, Gunnar: Early Middle Cambrian Fauna from Rogaland, SW Norway 13
Holtedahl, Olaf: Professor Hans Cloos. Minneord 204
Kvale, Anders: En etterlysning. Notis 212
Neumann, Henrich. Se Adamson.
Oftedahl, Christoffer: On "Apoanalcite" and Hydronephelite 1
Oftedal, Ivar: Meteorite-Collections in Hungary. Anmeldelse .. 213
Rosenqvist, Ivan Th.: Diffusjonsreaksjoner mellom pyritt og hematitt i finkornig sandstein 5
— De metamorfe fasies og feltspatmineralene. Foredragsreferat 214
Semb, G.: Iakttagelser fra en skjæring i Vestfoldraet ved Larvik. Notis 205
Skjeseth, Steinar: On the Lower Didymograptus Zone (3 B) at Ringsaker, and Contemporaneous Deposits in Scandinavia 138
Strand, Trygve: Occurrences of Zeolites in Nordmøre. Notis 210

Norsk geologisk forening.

Generalforsamling 1952 221
Regnskap for 1951 222
Medlemsliste, á jour juli 1952 224

Ikke refererte foredrag:

Adamson, Olge: Våre mineralske råstoffers geopolitiske betydning 214
Gjelsvik, Tore: Fra en reise i U. S. A. 220
Heintz, A.: Et nytt funn av mammutt-tann i Norge 220
Holmsen, Per: Fra Alpe-ekskursjonene 1950 223
Lundberg, Hans: Geofysisk malmleting fra luften 220
Oftedahl, Chr.: En tripp gjennom U. S. A. 220
Skjeseth, Steinar: Stratigrafi og tektonikk i Mjøstraktene . . 220
Thorarinsson, Sigurdur: Myvatn-områdets lavaströmmar och kratergrupper 214
Thorslund, P.: Släktet Robergias systematiska ställning 220

ON "APOANALCITE" AND HYDRONEPHELITE

BY

CHRISTOFFER OFTEDAHL[1]

Abstract. "Apoanalcite", proposed by the author as a new mineral, is shown to consist essentially of fibrous aggregates of natrolite, and should thus be discarded. Another component of "apoanalcite" is pseudo-hexagonal. It is supposed that what has been called hydronephelite consists of mixtures of natrolite aggregates and the pseudo-hexagonal mineral which is possibly what truly should be called hydronephelite.

Apoanalcite as a new mineral was proposed by the author (Oftedahl, 1947, p. 215) for a zeolite-like mineral, which was uniaxial positive, $\varepsilon = 1.487$, $\omega = 1.475$, and which had a chemical composition like that of analcite.

Later Neumann (1948, p. 171) pointed out that apoanalcite probably belongs to the mineral group hydronephelite-ranite. Recent x-ray investigations on the analyzed specimen by the present author indicate that the "apoanalcite" consists of natrolite and what is possibly an unknown mineral. Therefore, the term apoanalcite should be discarded.

Optics. Inasmuch as x-ray studies suggest that the specimen consists essentially of natrolite, a reinvestigation of optical properties was carried out. Under the microscope the red aggregate consists of 90 to 95 per cent of an apparently uniaxial mineral (natrolite), and 5 per cent of another zeolite-like mineral in small irregular patches, mostly about 0.05—0.1 mm across. On the universal stage the latter mineral proved to be biaxial, (—) $2V = 70—80°$, one cleavage plane parallel to XZ (i. e. monoclinic or possibly orthorhombic), N greater than Canada balsam, and $\gamma—\alpha$ about 0.013.

---

[1] The work was done in 1950 when the author was visiting assistant professor at the University of Illinois, Urbana, Illinois.

Careful measurements of the "uniaxial" mineral on the universal stage show that it is actually biaxial. Most of the small patches measured within the grains having strong undulatory extinction seem to be uniaxial according to the three tests described by Ingerson (Knopf and Ingerson, 1938, pp. 242—243). Some grains however, seem to have a dark sector instead of an axis, and two small patches have two axes with (—) 2V=22° and 54°, respectively, thus approaching the axial angle of natrolite (about 60°). The refractive indices are those generally given for natrolite. It is, therefore, logical to assume that the "uniaxial" mineral is an intergrowth of submicroscopical fibres of natrolite. These fibres have parallel c-axes, but have random orientation of their a and b axes, thus creating a pseudo-uniaxial symmetry. Support for this assumption is found from a tiny cylindrical grain (0.2 × 0.03 mm in size), which seems to be just one individual under the microscope. A Weissenberg zero-layer photograph shows that this grain consists of two natrolite individuals, with strictly parallel c-axes, but with the a- and b-axes 2—3° from each other.

This feature explains the observations by Brøgger (1890, II, p. 232) on the weathering products of nephelite from Langesundsfjord in the Oslo region, Norway. Brøgger distinguished between two varieties of "spreustein" formed from nephelite. One variety consists essentially of natrolite with subordinate amounts of hydronephelite, diaspore, analcite, etc.; another variety consists of hydronephelite, with some diaspore, thomsonite, etc. The varieties cannot be distinguished from each other, and even under the microscope they are very much alike, having the same refractive indices and parallel extinction. Only the axial section shows hydronephelite to be uniaxial, whereas natrolite is biaxial. However, the observations stated above by the present author suggest that both types of "spreustein" consist of natrolite, one being pseudo-uniaxial because of intergrowth of fibres.

The natrolite contains, besides small inclusions of iron ore, small patches of a clear, zeolite-like mineral to be discussed below.

X-ray work. The powder pattern of "apoanalcite" is identical with that of natrolite. The amount of the other silicate mineral is not sufficient to give noticible lines.

One little grain, picked out from "apoanalcite" powder gave an x-ray pattern different from natrolite. The pattern is pseudo-hexagonal, orthorhombic, or possibly monoclinic, pseudo-orthorhombic. Obviously it is the same mineral as the one observed as inclusions in the natrolite.

Weissenberg zero-layer photographs with c-axis rotation show some interesting details. The grain consists of two mineral individuals with slightly different unit cells. One cell is almost hexagonal in symmetry, with a_1, a_2, and a_3 along the pseudo-hexagonal axes equal to 6.32 Å, 6.35 Å, and 6.39 Å, respectively (± 0,03 Å). The corresponding dimensions of the other cell are 6.67 Å, 6.63 Å, and 6.50 Å, respectively. These dimensions are dependent on the assumption that the corresponding reflections are of first order. They might have to be doubled or tripled. Rotation photographs around the c-axis show that the c period of the two cells are 7.25 Å and 7.14 Å, respectively (± 0.03).

The pseudo-hexagonal symmetry of the above described mineral supports the assumption that it could be properly called hydronephelite, having a cell related to that of the hexagonal nephelite, even though its unit cell seems to be smaller than that of nephelite ($a = 10.1$ Å, $c = 8.5$ Å). At least it is not an ordinary zeolite, or diaspore or boehmite, which are frequently associated with natrolite.

Chemical Composition. If "apoanalcite" is composed of 90 to 95 % natrolite and 5 to 10 % of the unknown mineral, it should be possible to arrive at some approximate composition of the mineral by subtracting 90 % natrolite from the composition of "aponalcite" (see Oftedahl, 1947, p. 216). Such a calculation, however, gives approximately $10\,SiO_2 . Al_2O_3 . 40\,H_2O$, which can scarcely be any mineral. Therefore, the already published analysis must be somewhat erroneous.

The Hydronephelite Problem. It is still uncertain if the mineral hydronephelite exists. Only two analyses have been published in the later years. Walker and Parsons (1926, p. 11) gave the composition of what they thought was ranite, — a calcium-bearing hydronephelite with 5 % CaO. Later Dunham (1933, p. 373) published the composition of hydronephelite containing 3 % CaO. Dunham considered hydronephelite to be an aggregate, as did Thugutt (1932, p. 141). As suggested by Neumann (1948, p. 173) there might be a series from nephelite to "hydronephelite", that is, from nephelite to mixtures of natrolite and the pseudo-hexagonal mineral. The doubtful species ranite is probably a mixture of natrolite and some Ca-rich mineral.

For comparison, powder patterns were made of two samples of hydronephelite, one from Katzenbuchel, Odenwald, Germany, and one from Wausau,Wisconsin. On both samples the hydronephelite occurred on nephelite crystals as a reddish weathered zone, a few millimeters thick. The powder pattern of both specimens show lines from natrolite and from the pseudo-hexagonal mineral described above, in proportions of approximately 1 : 1. Further x-ray, optical or chemical studies are scarcely possible on these weathered materials. Therefore, investigations must be carried out on more favorable material in order to find out if any mineral like the hydronephelite described by Clarke (1896, p. 265) and Brøgger (1890, II, p. 232) really exists, or if this hydronephelite generally is a mixture of natrolite and a new pseudo-hexagonal mineral. If the latter case is true the name "hydronephelite" may be given to the pseudo-hexagonal mineral.

References.

Brøgger, W. C.: Die Mineralien der Syenitpegmatitgänge der süd-norwegischen Augit- und Nephelinsyenite. Zeitschr. Kryst., vol. *16,* 1890, Part II (Specieller Theil), pp. 1—663.

Dunham, K. C.: Crystal Cavities in Lavas from the Hawaiian Islands. Am. Min., vol. *18,* 1933, pp. 369—385.

Neumann, H.: On Apoanalcite. Norsk Geol. Tidsskr., vol. *27,* 1948, pp. 171—174.

Oftedahl, Chr.: Apoanalcite, A New Mineral. Norsk Geol. Tidsskr., vol. *26,* 1947, pp. 215—218.

Thugutt, St. J.: Sur l'epinatrolite, mineral composant l'hydronephelinite. Archive de mineralogie de la societé des sciences et des lettres de Varsovie, vol. *8,* 1932, pp. 141—144.

Walker, T. L., and A. L. Parsons: Minerals from the new nepheline syenite area, French River, Ontario. Toronto University Studies, Geological Series (Contributions to Canadian Mineralogy), 1926, pp. 5—14.

DIFFUSJONSREAKSJONER MELLOM PYRITT OG HEMATITT I FINKORNIG SANDSTEIN

AV

IVAN TH. ROSENQVIST

Abstract. A peculiar reddish sandstone containing light greenish ellipsoids is investigated. It is concluded that the ellipsoids have been formed during the metamorphism by reactions between pyrite and haematite of the original sediments. The red.-ox.-reactions have been investigated from an energetical point of view.

I sedimentene under toppen av fjellet Skogshorn i Hemsedal finnes en del eiendommelige røde leirsandsteiner. Dette bergartskompleks er beskrevet av Carl Bugge (N. Geol. U. Nr. 153 1939), som henfører det til Melsennavdelingen. De spesielle forhold som her skal behandles er ikke beskrevet av Bugge.

Langs hele sydsiden av det bratte stup som danner glintranden finnes en blåsvart, finkornig, grafittførende leirskifer, som på sine steder er utviklet som takskifer. Gjennom tidene har det vært drevet en del takskiferproduksjon for lokalt forbruk, og i ganske liten utstrekning også til eksport ut av bygden.

Denne takskifer er til dels svovelkisførende, og langs enkelte plan kan den derfor være ganske rusten. Stort sett er det imidlertid frisk pyritt i alle grafittførende partier. Det er åpenbart at den bituminøse skifer har virket som reduksjonsmiddel, slik at surstoffoverskudd i eventuelle sirkulerende oppløsninger er medgått til oksydasjon av det bituminøse materiale, og ikke har angrepet pyrittkrystallene. I nærheten av skyvekontakten mot saussurittgabbroen, som utgjør toppen av fjellet, er sedimentbergarten på sine steder litt grovere, med gjennomsnittlig kornstørrelse et par μ, og størrelsen opp til 0,05 mm. I disse partier finnes ikke bituminøst materiale. Bergarten er meget vakkert rødfiolett pigmentert. De mineraler som kan identifiseres er kvarts, mikroklin, sericitt, og meget lite biotitt. Hovedmengden av mineralene er imidlertid så finkornige at de ikke kan identifiseres i mikroskop.Lysbrytningen synes stort sett å være moderat, og særlig meget mørke mineraler forekommer sikkert ikke. Hele pigmenteringen antas å skyldes en meget lav prosentsats av uhyre finkornig hematitt og noen meget få, litt større magnetittkorn. Det som gjør denne bergart påfallende er at den meget ofte er spettet med ovale, svakt grønnlig fargete flekker. Det ser ofte ut på spalteflatene som det skulle være skvettet maling på bergarten. Undersøker man imidlertid fenomenet nøyere, finner man at flekkene er dannet ved at bergarten er gjennomsatt av grønnlige ellipsoider med gjennomsnittlig relativt akseforhold = 1 : 2,5 : 3,75. Uansett flekkenes størrelse synes dette forhold å gjelde. Flekkene varierer i størrelse fra ca. 2 mm lengste akse til ca. 30 mm lengste akse. I noen enkelte tilfelle er flekkene større, men synes da å være bygget opp av flere ellipsoider som er vokset sammen.

Fig. 1 viser typiske flekker på skifrighetsplanet. Fig. 2 viser et tverrsnitt av skiferen, skåret i planet av de to mindre akser.

I mikroskopet viser flekkene seg å være lite forskjellige fra bergarten forøvrig. Forskjellen består bare i at det karakteristiske pigment mangler nesten fullstendig i de lyse partier. Fig. 3 viser mikrofoto av en liten lys flekk med liten forstørrelse. Fig. 4 viser grensen mellom den samme flekk og den pigmenterte bergart. Forstørrelsen er her 80×.

Det er en slående forskjell mellom de bituminøse skifre som ikke fører hematitt, men derimot pyritt, og de bitumenfri skifre som fører hematitt, men ikke pyritt. Dette forhold gjør det naturlig å anta at de lyse flekker er oppstått ved en eller annen red.-oks.-reaksjon mellom hematitt og pyritt. Denne reaksjon har vært av en slik art at begge faser er forsvunnet. Årsaken til at hematitt overhodet finnes i en sur silikatbergart, er at det bare er meget begrensete mengder treverdig jern som kan inngå i de vanlige silikatmineraler. Det eneste bergartsdannende silikatmineral som under disse termodynamiske betingelser kan oppta nevneverdige mengder Fe^{III} er epidot. Rimeligvis på grunn av lavt kalkinnhold finnes det ikke epidotmineraler i den behandlete bergart, på tross av at metamorfosegraden antyder trykk- og temperaturforhold svarende til Eskola's epidot-amfibolittfacies (saussurittfacies, lavgneisfacies). Når det gjelder toverdig jern på den annen side, så kan dette jern med letthet opptas i en rekke silikatmineraler. Det totale jerninnhold som finnes som hematittpigment i de røde skifre er i virkeligheten meget beskjedent, og dersom det hadde

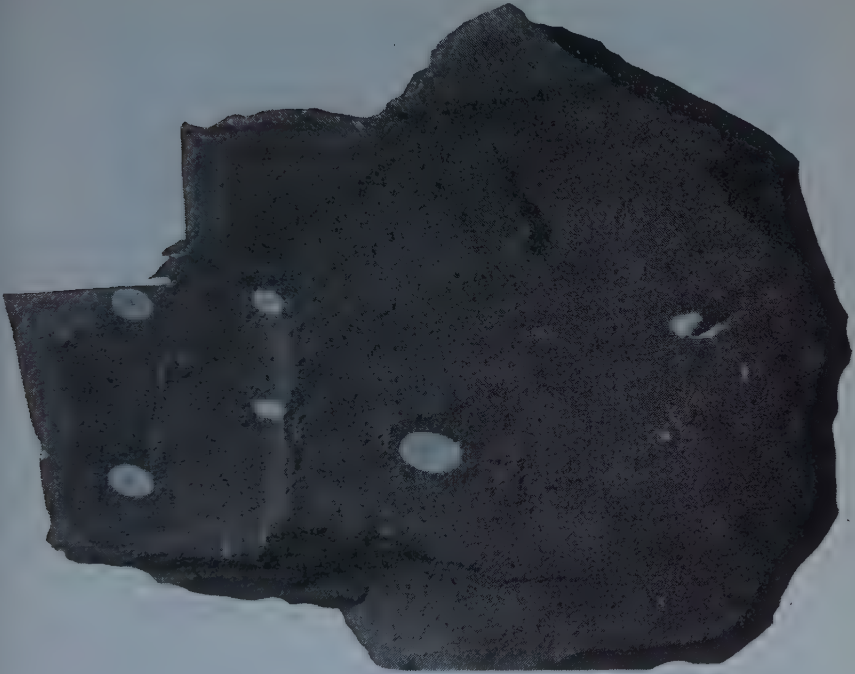


Fig. 1. Sandsteinskifer fra Skogshorn med lyse spetter.
½ naturlig målestokk.

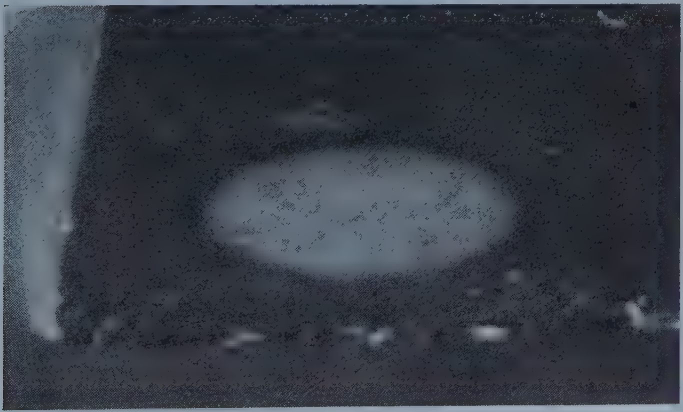


Fig. 2. En lys flekk skåret på tvers av skifrigheten i planet av de to minste akser i ellipsoidet. 11 × forstørret.

Fig. 3. En lys flekk 11 × forstørret skåret parallelt skifrigheten.

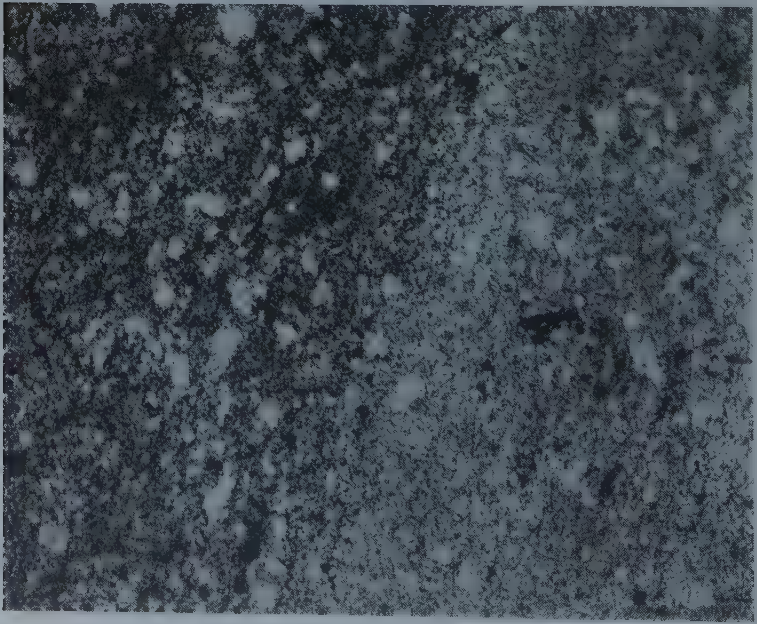


Fig. 4. Grensen mellom den rødpigmenterte sandstein og de lyse ellipsoider. 80 × forstørret.

foreligget i toverdig form, ville mengden av mørke mineraler neppe blitt merkbart endret på grunn av dette jerninnhold.

Det synes for meg rimelig at de grønne spetter er oppstått ved at pyritten på en eller annen måte har redusert hematitten til toverdig jern, som så har gått inn i silikatfasen. Samtidig er pyritten oksydert til toverdig jernsulfat. Metamorfosegraden tyder på at temperaturen for denne reaksjon har vært mellom ca. 450° K og 650° K. Undersøker vi de forskjellige reduksjons-oksydasjons-reaksjoner energetisk med henblikk på reaksjonstemperaturen, har vi anledning til å fastslå hvilke reaksjoner som har vært mulige.

De mest nærliggende reaksjoner er:

I. $FeS_2 + 7\,Fe_2O_3 \rightleftarrows 2\,FeSO_4 + 13\,FeO$

II. $FeS_2 + 5\,Fe_2O_3 + O_2 \rightleftarrows 2\,FeSO_4 + 9\,FeO$

III. $FeS_2 + 3\,Fe_2O_3 + 2\,O_2 \rightleftarrows FeSO_4 + 5\,FeO$

Vi vil undersøke disse reaksjoner med hensyn til variasjon i fri energi i temperaturintervallet 300° K—1000° K. Jeg vil her benytte anledningen til å takke laboratoriesjef Egil Ronæss for den hjelp han har ytet meg med å finne fram og beregne nedenstående verdier for Δ F.

Vi ser av disse oppstillinger over Δ F at mens reaksjoner etter likning I vil forløpe mot venstre, og ikke gi opphav til de lyse flekker selv ved så høye temperaturer som 1000° K, så forløper prosessen etter likning II mot høyre ved temperaturer over 500° K, og etter likning III selv ved meget lave temperaturer.

Tilstedeværelsen av fritt surstoff vil være minimumsfaktoren for reaksjonene.

Da det som nevnt er grunner som taler for at temperaturen under metamorfosen ikke har vært under ca. 450° K — snarere en del høyere — kommer en til at reaksjonen etter all sannsynlighet har funnet sted i henhold til likning II. Denne reaksjon krever bare halvparten av den mengde surstoff som er nødvendig etter likning III.

En viktig konklusjon som kan trekkes av disse undersøkelser er at det i bitumenfri sandsteiner og skifre kan finnes fritt surstoff under metamorfosebetingelser svarende til Eskola's epidot-amfibolitt-facies. Dette surstoff må være av atmosfærisk opprinnelse, og bibeholdt i sedimentet i ubunden form etter sedimentasjonen, rimeligvis oppløst i porevannet.

Likning I.

T °K	$FeS_2 + 7 Fe_2O_3$		$\rightleftarrows$	$2 FeSO_4 + 13 FeO$		
	Δ F Kcal	Δ F Kcal	Σ Δ F	Δ F Kcal	Δ F Kcal	Σ Δ F
300	—55.3	—1253.0	—1308.3	—412.0	—767.0	—1179.0
400	—50.5	—1207.5	—1258.0	—391.6	—743.6	—1135.2
500	—45.8	—1163.2	—1209.0	—370.6	—722.8	—1093.4
600	—41.0	—1120.0	—1161.0	—349.6	—702.0	—1051 6
700	—36.3	—1076.6	—1112.9	—328.4	—681.2	—1009.6
800	—31.7	—1013.9	—1045.6	—306.8	—660.4	— 967.2
900	—27.1	— 992.6	—1019.7	—285.4	—639.6	— 925.0
1000	—22.5	— 951.3	— 973.3	—263.8	—618.8	— 882.4

Likning II.

T °K	$FeS_2 + 5 Fe_2O_3 + O_2$		$\rightleftarrows$	$2 FeSO_4 + 9 FeO$		
	Δ F Kcal	Δ F Kcal	Σ Δ F	Δ F Kcal	Δ F Kcal	Σ Δ F
300	—55.3	—895.0	—950.3	—412.0	—531.0	—942.0
400	—50.5	—862 5	—912.0	—391.6	—514.8	—906.4
500	—45.8	—831.0	—876.8	—370.6	—500.4	—871.0
600	—41.0	—800.0	—841.0	—349.6	—486.0	—835.6
700	—36.3	—769.0	—805.5	—328.4	—471.6	—800.0
800	—31.7	—738.5	—770.2	—306.8	—457.2	—764.0
900	—27.1	—709.0	—736.1	—285.4	—441.8	—728.0
1000	—22.5	—679.5	—702.0	—263.6	—428.4	—692.0

Likning III.

T °K	$FeS_2 + 3 Fe_2O_3 + 2 O_2$		$\rightleftarrows$	$2 FeSO_4 + 5 FeO$		
	Δ F Kcal	Δ F Kcal	Σ Δ F	Δ F Kcal	Δ F Kcal	Σ Δ F
300	—55.3	—537.0	—592.3	—412.0	—295.0	—707.0
400	—50.5	—517.5	—568.0	—391.6	—286 0	—677.6
500	—45.8	—498.6	—544.4	—370.6	—278 0	—648.6
600	—41.0	—486.0	—527.0	—349.6	—270.0	—619.6
700	—36.3	—461.4	—497.7	—328.4	—262.0	—590.4
800	—31.7	—443.1	—474.8	—306.8	—254.0	—560.8
900	—27.1	—425.4	—452.5	—285.4	—246.0	—531.4
1000	—22.5	—407.7	—430.2	—263.6	—238.0	—501.6

Ved likning II ser en at forskjellen i fri energi ved atmosfæretrykk er forholdsvis liten. Beregnes likevektstrykket $p = \exp \frac{RT}{\Delta F}$ finner en: 300°, p = ca. 10^6 atm.; 400°, p = ca. 10^3 atm.; 500°, p = ca. 350 atm.; 600°, p = ca. 90 atm.; 700°, p = ca. 60 atm.; 800°, p = ca. 50 atm.; 900°, p = ca. 80 atm.; 1000°, p = ca. 160 atm.

Formen av de reduserte soner viser klart at det her ikke har vært tale om noen strømning av væskefasen under reaksjonen. I så fall ville den blekete sone hatt et mer eller mindre pæreformet eller langstrakt utseende, og en diffus tiltaking av pigment i de deler som ligger lengst fra det reduserende pyrittkorn. Reaksjonene hadde i så tilfelle måttet forløpe i to trinn, nemlig:

IV. $FeS_2 + 2\frac{1}{2}\ O_2 \rightarrow FeO + 2\ SO_2$
V. $Fe_2O_3 + SO_2 \rightarrow FeSO_4 + FeO$

I dette tilfelle ville det ha medgått ennå mer surstoff enn det trengtes etter likning III. Selv om en slik prosess som skissert i likning IV og V energetisk er mulig, viser det mikroskopiske bilde tydelig at reduksjonen har bredd seg symmetrisk ut fra et sentrum i et ellipsoid. Dette viser igjen at det her dreier seg om diffusjonsprosesser i stillestående medium. I alt overveiende del har diffusjonen vært bestemt av de intergranulare passasjer. Som det kan sees av fig. 3, har bergarten en viss linjestruktur i skifrighetsplanet. Linjestrukturene faller sammen med ellipsoidenes lengste akse. Av denne grunn vil det være best passasje og størst samlet tverrsnitt av intergranulare åpninger i denne retning. Retningen loddrett på denne vil i skifrighetsplanet ha minimum av samlet tverrsnitt for intergranular passasje, mens retningen loddrett på skifrighetsplanet vil ha ennå mindre samlet tverrsnitt av intergranulare passasjer.

Dersom diffusjonsprosessene i det vesentlige hadde foregått gjennom de faste faser, ville det ikke ha vært noen innlysende grunner til at det skulle oppstå slik utpreget anisotropi i den reduserte sone.

Den stenglige orientering av mineralene i bergarten kan vanskelig antas å være primær, men skyldes sikkert metamorfosen. Herav kan en derfor slutte at reduksjons-oksydasjons-prosessene har satt inn etter at metamorfosen i det vesentlige hadde bevirket rekrystallisasjonen og orienteringen av silikatmineralene.

Hele tolkningen av de grønnlige spetter i den røde Melsennskifer viser en progressiv metamorfose av et oksyd- og sulfidholdig sediment, noe som igjen sannsynliggjør at reaksjonen har funnet sted etter likning II, idet denne reaksjon som nevnt først setter inn ved temperaturer litt under 500° K, eller svarende til overgangen mellom grønnskiferfacies og epidot-amfibolittfacies.

Det er bemerkelsesverdig at et reduksjonsmiddel som pyritt og et oksydasjonsmiddel som hematitt er stabile ved siden av hverandre ved alle normale metamorfosetemperaturer, dersom det ikke tilføres atmosfærisk surstoff. Dette forklarer hvorfor man hyppig kan påtreffe slike parageneser i fjellkjedens metamorfe malmer.

I de tilfelle hvor de to nevnte mineraler har reagert med hverandre, må man alltid anta at surstofførende oppløsninger enten har vært til stede i et opprinnelig sediment, eller at vadost vann har kunnet trenge ned til bergartene. Detkreves temperaturer på henimot 500° K, tilsvarende ca. 220° C, for at reduksjons-oksydasjons-prosessen etter likning II skal foregå. Det er lite trolig at atmosfærisk surstoff kan tilføres i nevneverdig grad, idet denne temperatur jo svarer til et dyp av ca. 8 km. Man må i alminnelighet anta at det atmosfæriske surstoff vil være oppbrukt til oksydasjon av reduserende substans før eventuelt nedtrengende vann når et slikt dyp.

Finner man at de to mineraler har reagert med hverandre slik som i Melsennskiferen ved Skogshorn, kan dette tas som bevis for at sedimentet har inneholdt betydelige O_2-mengder, enten oppløst i vann eller som luftinneslutninger.

Den geokjemiske reduksjonsvirkning av slikt atmosfærisk luftinnhold i sedimenter under metamorfosen har, så vidt det kan sees, ikke vært tatt særlig i betraktning tidligere.

Summary.

In the sediments near the mountain Skogshorn in Hemsedal some reddish fine-grained sandstones are found together with bluish-black slates. In the slates, which contain bituminous material, pyrite is present. In the reddish sandstones no pyrite is found, but it is made probable that some peculiar ellipsoids of light greenish colour have been formed by reaction between sedimentary pyrite and the haematite pigment of the rock. Different possible reactions have been investigated from an energetical point of view. It is concluded that the most possible reaction is: $FeS_2 + 5\,FeO_3 + O_2 \rightleftarrows 2\,FeSO_4 + 9\,FeO$.

The direct reaction between pyrite and haematite does not take place at the temperatures of ordinary metamorphism. The reduction of the haematite is found to have occurred after a certain recrystallization of the silicate minerals. This means that during the initial metamorphism no red.-ox. reaction took place. The free energies for the different reactors in the temperature interval between 300° K—1000° K is tabulated.

It is concluded that the necessary oxygen must have been of sedimentary origin, either dissolved in the water or as inclusion of air.

EARLY MIDDLE CAMBRIAN FAUNA FROM ROGALAND, SW NORWAY

(Paradoxides oelandicus stage = 1c α)

BY

GUNNAR HENNINGSMOEN

Contents.

Abstract 13
Introduction 13
The fossils 15
  Trilobitae 15
    Peronopsis fallax (Linnarsson) 15
    Paradoxides pinus Westergård 16
    Paradoxides oelandicus Sjögren 16
    Ptychoparia anderseni sp. n. .. 17
  Brachiopoda 19
    Orthoid brachiopod 19
    Lingulella sp. 19
    Acrothele (Redlichella) granulata Linnarsson 20
    Acrotreta socialis v. Seebach .. 21
  Hyolitha 22
    Hyolithes obesus Holm 22
    Orthotheca teretiuscula (Linnarsson) 22
  Porifera 23
    Protospongia? sp. 23
    Chancelloria sp. 23
  Problematica 24
Discussion of fauna 24
List of fossils from the *Paradoxides oelandicus* stage in Norway 26
Kambriske fossiler fra Rogaland 28
References 29
Explanation of plates 32

Abstract. Cambrian fossils have, for the first time, been found on the west coast of Norway. They were found by cand. real. Bjørn Andersen in 1949 at Ritland, Hjelmeland district, Rogaland County. The fossils occur in autochthonous dark shale, and belong to the *Paradoxides oelandicus* stage (Early Middle Cambrian). Trilobites (including *Ptychoparia anderseni* sp. n.), brachiopods, hyolithids, sponge needles, and problematica (including archaeocyathids?) have been collected. The absence of this stage in the autochthonous series in the Oslo region, as well as in the Swedish areas Västergötland and Scania, suggests a land mass in these areas in *P. oelandicus* time, bordered to the north by the Caledonian geosyncline, and to the east by a shallow sea.

Introduction.

While geologically mapping in the northern part of Rogaland County (SW Norway) in the summer 1949, cand. real. Bjørn Andersen found a piece of shale containing the impression of a trilobite (*Paradoxides pinus*, pl. 1, figs. 3—4), and thus discovered a locality for Cambrian fossils farther west than any other known locality in Norway. More fossils were collected later. They were all found in situ or in loose blocks in a few collecting grounds near to each other on a steep mountainside less than 1 km west of the houses of the property Ritland in Hjelmeland district at Jøsenfjord, c. 50 km NW of Stavanger.

The locality is inside the area of Caledonian overthrusts, but the fossiliferous shale is autochthonous (or parautochthonous). The nearest locality with Cambrian fossils within the Caledonian mountain chain area is Usteberget at Ustaoset (Uppermost Lower Cambrian, cf. Størmer, 1925), some 160 km to the NE. The nearest occurrence of Cambro-Silurian outside the Caledonian mountain chain is in the Skien-Langesund area in the Oslo region, some 180 km to the east. The only other known locality for prequaternary fossils in Rogaland is Skudenes, on the island Karmøy, some 65 km west of Ritland. According to Strand (in Broch a. o., 1940), the fossiliferous beds are most probably of Upper Ordovician age.

After finding the first fossil, cand. real. Bjørn Andersen soon found more, and on that and later occasions collected fragments of *Paradoxides* (one identified as *P. oelandicus*), inarticulate brachiopods, hyolithids, sponge needles, and problematic fossils. Cand. real. Nils Spjeldnæs, together with Bjørn Andersen, collected more of the same fossils in the summer 1950, as well as some additional forms; *Peronopsis fallax* and articulate brachiopods. Curator Holger Holgersen also visited this locality in 1950 and collected inarticulate brachiopods, hyolithids, *Paradoxides* remains and an almost complete dorsal shield of *Ptychoparia anderseni* sp. n. The counterpiece of this trilobite was later found by Mr. Tor Ritland.

The fossils collected by Curator H. Holgersen belong to Stavanger Museum, whereas all the others belong to Paleontologisk Museum in Oslo. The writer expresses his grateful thanks to Professor A. Heintz, (Paleontologisk Museum, Oslo) and Curator H. Holgersen (Stavanger Museum), who placed the fossils at his disposal.

The fossils are preserved in a dark, grey-streaked shale, comparatively little altered considering that it occurs in the Caledonian mountain chain area. There are at present too few data to permit a safe determination of the vertical distribution of the fauna; probably it is between 30 and 60 m.

The manuscript has kindly been revised by Miss Jill Murray.

THE FOSSILS

TRILOBITAE

Superfamily **Agnostacea** Salter, 1864.
Family **Agnostidae** (Corda, 1847) M'Coy, 1849.[1]
Subfamily **Peronopsinae** Westergård, 1936.
Genus *Peronopsis* Corda, 1847 (type species: *Battus integer* Beyrich, 1845).

Peronopsis fallax (Linnarsson, 1869) — Pl. 2, fig. 5.

1936. *Peronopsis fallax* (Linnarsson) — Westergård, Parad. œland. Beds of Öland, p. 28, pl. 1, figs. 9—15. (List of synonymy, remarks on species.)

1946. *Peronopsis fallax* (Linnarsson). — Westergård, Agnostidea, p. 37, pl. 2, figs. 18—24. (Remarks on species.)

Remarks: — Only one cephalon and one pygidium have been found, lying close together and probably from one individual. They are only impressions, and the preservation is not too good. However, the long pygidial axis, reaching the posterior rim, and other characters agree with the form of *Peronopsis fallax* occurring in the *Paradoxides pinus* beds in Sweden, so that the Rogaland shields can be safely assigned to this species.

Superfamily **Redlichiacea** Richter, 1932.
Family **Paradoxididae** Emmrich, 1839.
Subfamily **Paradoxidinae** Emmrich, 1839 (subf.: Howell, 1933).
Genus *Paradoxides* Brongniart (type species: *Entomostracites paradoxissimus* Wahlenberg, 1821).

---

[1] M'Coy, 1849 has usually been credited for this family. The first to erect agnostid families was, however, Corda, 1847, who erected the families Battoides and Phalacromides. (Battus Dalman, 1827 is a synonym for *Agnostus* Brongniart, 1822.) Agnostidae is then only a new name for Battoides.

Paradoxides pinus Westergård, 1936.[1] — Pl. 1, figs. 3—4.

cf. 1929. *Paradoxides* cf. *pinus* Holm in museo — Strand, Cambr. Beds Mjøsen, p. 350. (Recorded from the Hadeland district.)
1936. *Paradoxides pinus* Holm ms. — Westergård, Parad. œland. Beds Öland, p. 38, pls. IV—VI. (Description, also of larval stages.)
cf. 1948. *Paradoxides* cf. *pinus* Holm — Strand, Middle Cambr. Hadeland, p. 92 (Mentions the find which was briefly described in 1929.)

Remarks: — The first fossil found at Ritland, a damaged dorsal shield of *Paradoxides* (and its counterpart), belongs to this species. The pygidium is not well preserved, but the posterior pleurae show clearly the characteristic feature of this species; the pleural spines in the most posterior segments being about equal in breath to the part of the pleurae inside the fulcrum, and not expanded. Probably a number of other fragments of *Paradoxides* also belong to this species, as well as to the next species.

Occurrence: — Norway (Rogaland, Hadeland?), Sweden.

Paradoxides oelandicus Sjögren, 1872 — Pl. 1, fig. 1.

1872. *Paradoxides Oelandicus* n. sp. — Sjögren, Ölands Kambr. lager. p. 72, pl. 5, fig. 1. (Description.)
1877. *Paradoxides ölandicus* Sjögren — Linarsson, Lagren med Parad. öland., p. 3 (345), pl. I (14), figs. 1—6. (Description.)
1882. *Paradoxides Ölandicus* Sjögren — Brøgger, Parad. Öland. nivået ved Ringsaker, p. 146. (Recorded from Ringsaker in the Mjøsa district.)
1929. *Paradoxides ölandicus* Sjögren — Strand, Cambr. Beds Mjøsen, p. 350. (Recorded from the Mjøsa and Hadeland districts.)
? 1929. *Paradoxides* n. sp. — Strand, *idem,* p. 350. (Short description of pygidium from the Mjøsa district.)
? 1934. *Paradoxides* cf. *oelandicus* Sjögren — Cobbold, Cambr. area of Rushton, p. 348, p. 42, figs. 4—6. (Records fragments possibly belonging to the *oelandicus* group.)
? 1935. *Paradoxides ölandicus*? Sjögren — Lake, Brit. Cambr. trilob., p. 224. (Mentions Cobbold's material, which is stated to be quite insufficient to determine the species.)
1936. *Paradoxides œlandicus* Sjögren — Westergård, Parad. œland. Beds Öland, p. 33, pl. II, figs. 1—11, pl. III, figs. 1—6. (Supplementary description.)
1948. *Paradoxides* cranidia of *oelandicus* type. — Strand, Middle Cambr. Hadeland, p. 92. (Records the find mentioned in 1929.)

---

[1] According to article 25 of the "rules", Westergård is the author of the species.

Remarks: — A *Paradoxides* fragment consisting of the posterior part of the thorax and the pygidium is of the *oelandicus* type. The pygidium is of the *oelandicus* rather than the *quadrimucronatus* form, being only slightly longer than wide. The specimen may be assigned to *P. oelandicus.*

The pygidium referred to by Strand (1929) as *Paradoxides* n. sp. is very large (3 cm long), indicating a length of the dorsal shield of over 20 cm. The pygidium is of the *oelandicus* type, but has two pairs of smaller spines between the outer pair of spines, instead of only one pair, and is granulated. It recalls a pygidium figured by Westergård (1936, pl. III, fig. 10) as a "variety of *P. oelandicus*?", but Strand's specimen has a shorter axis. It is possible that it represents a variety of *oelandicus,* as is also suggested for *quadrimucronatus* by Westergård (1936, p. 36).

Occurrence: — Norway (Rogaland, Hadeland, Ringsaker), Sweden, Great Britain?

Superfamily **Conocoryphacea** Swinnerton, 1915.
Family **Conocoryphidae** Angelin, 1854.
Subfamily **Ptychopariinae** Matthew, 1887.
Genus *Ptychoparia* Corda, 1847 (type species: *Conocephalites striatus* Emmrich, 1839).

Ptychoparia anderseni sp. n. — Pl. 2, figs. 1—2.

Name: — The name is given in honour of cand. real. Bjørn Andersen, who discovered the Oelandicus beds in Rogaland.

Holotype: — PMO. 66300, a cephalon and 12 thoracic segments, preserved as an external mould. The fossil itself (SM. 1951/53) has also been found, but is less well preserved.

Other material: — SM. 1951/54, an external mould showing parts of the occipital region and 13 thoracic segments.

Diagnosis: — *Ptychoparia anderseni* sp.n. is like the type species, but differs in having the fulcrum much nearer the axis, a coarser granulation of the test, and more rapidly narrowing glabella.

Description: — Entire trilobite probably sub-oval in outline (pygidium not known). Axial lobe strongly convex; inner parts of pleural lobes flattened, outer parts bent down.

Cephalon sub-semicircular in outline with genal angles drawn out to spines, marginal border raised in front, and with deep marginal, axial, and occipital furrows around the convex cheeks and glabella. Glabella (including occipital ring) narrowing forwards, rounded at front. Surface not well preserved, but at least two pairs of short oblique glabellar furrows can be discerned. Width of glabella about three-quarters its length. Sagittal length of occipital ring about one-quarter the length of entire glabella. Eyes situated midway between anterior and posterior margins, but closer to glabella than to lateral margin. Ocular ridges oblique, fairly strong. Anterior branches of facial sutures not well preserved, but apparently cutting anterior margin nearly in front of the eyes. Posterior branches bend out and back to cut posterior margin at a distance from the axial furrows slightly less than transverse width of occipital ring. Intra-ocular parts of fixed cheeks (width between one-half and two-thirds that of glabella between eyes) slope down towards glabella, whereas post-ocular parts ("posterior limbs"), free cheeks, and the pre-glabellar field bend down outwards. Free cheeks about as wide as glabella, with genal angles prolonged into strong, but not very long spines continuing curve formed by outer margin.

Hypostome and doublures unknown.

Thorax. Number of segments not known. The holotype shows 12 segments preserved, whereas the other specimen (SM. 1951/54) has 13, which may possibly be the total number of thoracic segments, as in the type species. Axial lobe somewhat more than one-quarter the width of thorax. Axial rings strongly raised. Inner parts of pleurae flattened, rising slightly to the fulcrum, situated less than halfway out from axial lobe at a distance from it considerably less than width of axial lobe. Outer parts of pleurae bending down and ending in short posterolaterally directed points. Pleural grooves deep and wide, deepest at the fulcrum. Ridges in front of and behind grooves very prominent, especially posterior ridge at the fulcrum.

Pygidium unknown.

Ornament sporadically preserved. Fixed cheeks and possibly glabella covered by fairly large tubercles, the distance between their centers being about 0.5 mm. The interspace seems to be densely covered by very fine tubercles. Free cheeks and pre-glabellar field ornamented with branching and anastomising ridges. Thorax covered with coarse and possibly also fine tubercles, as are the free cheeks.

Pleural ridges each bearing one row of coarse tubercles, whereas axial rings appear to bear at least three rows. No occipital or axial spines seem to be present.

Dimensions: — The holotype is of maximum width 2.4 cm at the posterior margin of the cephalon. Length unknown, but may be estimated to have been at least 3 cm. Length of head 1.1 cm, genal spines excluded. Length of thorax preserved (12 segments) 1.6 cm. Length of thorax in the other specimen (SM. 1951/54) with 13 segments, c. 1.7 cm.

Affinities: — *Ptychoparia striata,* the type species, resembles rather much *P. anderseni* sp. n. (cf. diagnosis, p. 17). *P. striata* has some of its characters more accentuated; in agreeance with this *P. anderseni* sp.n. probably is an earlier species than *P. striata*. *P. anderseni* sp. n. also reminds one of North American genera like *Clappaspis* Deiss, 1939 and *Elrathia* Walcott, 1924, which are probably fairly closely related to *Ptychoparia,* but seem to have more thoracic segments (cf. figs. in Resser, 1939).

Occurrence: — Norway (Rogaland).

BRACHIOPODA

Order **Protremata** Beecher, 1891.
Superfamily **Orthacea** Walcott, 1908.

Orthoid brachiopod. — Pl. 2, fig. 6.

A few defective valves of an orthoid brachiopod have been found. The best preserved specimen is figured. An orthoid brachiopod is recorded by Westergård (1936, p. 25) from the Oelandicus Beds in Sweden.

Order **Atremata** Beecher, 1891.
Superfamily **Obolacea** Schuchert, 1896.
Family **Obolidae** King, 1846.
Genus *Lingulella Salter,* 1866 (type species: *Lingula davisi* M'Coy, 1846).

Lingulella sp. — Pl. 2, fig. 4.

A single ventral valve (external impression) of a *Lingulella* sp. has been collected. The preservation is not too good, and the anterior part is split off to a lower plane than that of the edge of the valve, probably making the anterior part appear more acute (and slightly shorter) than it was. The preserved part is 12 mm long. An 8 mm long *Lingulella*? sp. is recorded by Westergård (1936, p. 23) from the Oelandicus Beds in Sweden.

Order **Neotremata** Beecher, 1891.
Superfamily **Acrotretacea** Schuchert, 1896.
Family **Acrotretidae** Schuchert, 1893.
Genus *Acrothele* Linnarsson, 1876.
Subgenus *Redlichella* Walcott, 1908 (type species: *Acrothele granulata* Linnarsson, 1876).

Acrothele (Redlichella) granulata Linnarsson, 1876 — Pl. 2, fig. 3.

1876. *Acrothele granulata* n. sp. — Linnarsson, Brach. of the Parad. Beds, p. 24, pl. IV, figs. 51—52. (Description, figs. of both valves.)
1877. *Acrothele granulata* Linrs. — Linnarsson, Lagren med Parad. oeland., p. 22, pl. 2, fig. 12. (Revised description of ventral valve.)
1912. *Acrothele (Redlichella) granulata* (Linnarsson) — Walcott, Cambr. Brach., p. 663, pl. LVI, figs. , 2 a—n. (Description, figs. of both valves.)
1923. *Acrothele (Redlichella) granulata* (Linnarsson) — Hedström, Remarks on some fossils from .. Visby, p. 10, pl. I, figs. 14 a—c. (Figs. of dorsal valve.)
1929. *Acrothele (Redlichella) granulata* (Lnrs.) — Strand, Cambr. Beds Mjøsen, p. 341. (Listed, with a few notes.)
1934. *Acrothele (Redlichella) granulata* (Linnarsson) — Cobbold, Cambr. area Rushton, p. 330. (Recorded from the Rushton area.)
1936. *Acrothele (Redlichella) granulata* (Linnarsson) — Westergård, Parad. œland. Beds Öland, p. 24. (Recorded. Notes on vertical and geographical distribution.)
1942. *Acrothele (Redlichella) granulata* Linnarsson — Poulsen, Nogle hidtil ukendte Fossiler fra Bornholms Exsulanskalk, p. 216, pl. p. 235, figs. 7—11. (Figs. of fragments of ventral valve.)

Remarks: — A number of more or less fragmentary preserved valves have been collected. They agree well with the Swedish form.

Occurrence: — Norway (Rogaland, Ringsaker), Sweden, Denmark (Bornholm), Great Britain.

Genus *Acrotreta* Kutorga, 1848 (type species: *A. subconica* Kutorga, 1848).

Acrotreta socialis v. Seebach, 1865.

1865. *Acrotreta socialis* — v. Seebach, Geol. d. Insel Bornholm, p. 341. (Figs. of both valves.)
?1867. *Acrotreta socialis* v. Seebach — Linnarsson, Brach. of the Parad. Beds, p. 16, pl. III, figs. 32—35. (Description, figs. of both valves. By Walcott, 1912, referred to *A. schmalenseei.*)
?1902. *Acrotreta schmalenseei* n. sp. — Walcott, Cambr. Brach., p. 597. (Linnarsson's "*Acrotreta socialis*" described as a new species.)
?1912. *Acrotreta schmalenseei* Walcott — Walcott, Cambr. Brach., p. 709, pl. LXX, figs. 1, 1 a—s. (Description, figs. of both valves.)
1912. *Acrotreta socialis* von Seebach — Walcott, Cambr. Brach., p. 711. (Description, figs. of both valves.)
?1921. *Acrotreta socialis* Seebach(?) — Cobbold, Cambr. horizons of Comley, p. 347, pl. XXII, fig. 35. (Description, figs. of both valves.)
?1929. *Acrotreta schmalenseei* Walc. — Strand, Cambr. Beds Mjøsen, p. 341. (Listed from the Mjøsa district after Walcott.)
?1934. *Acrotreta socialis* von Seebach — Cobbold, Cambr. Beds Rushton, p. 331. (Lists same form as at Comley.)
?1936. *Acrotreta schmalenseei* Walcott — Westergård, Parad. œland, p. 24. (Suggests that this species may not be distinct from *A. socialis.*)
1936. *Acrotreta socialis* v. Seebach — Westergård, *idem.*, p. 25.

Remarks: — In some slabs the bedding planes are covered by valves of *Acrotreta,* which are more or less distorted. Some of the better preserved specimens agree very well with the description of *A. socialis.* This species differs, according to Walcott (1902, 1912), from *A. schmalenseei* in having a rather strong and broad median groove of the false area, whereas it is absent or faint and shallow in *A. schmalenseei.* The latter form is also present in the Rogaland material. There appear to be intermediate forms as well, as in Westergård's material, and it is probable that *A. schmalenseei* should be regarded as a synonym for *A. socialis,* as suspected by Westergård (1936).

Occurrence: — Norway (Rogaland, Ringsaker), Sweden, Denmark (Bornholm), Great Britain?

HYOLITHA

Since the hyolithids most probably should not be assigned to the Pteropoda (cf. Wenz, 1938, p. 39), they are here assigned to a separate group.

Family **Hyolithidae** Nicholson.

A large number of hyolithids have been collected, but the preservation is not good. The specimens are more or less compressed, and rarely show any ornament. Two species have been fairly safely determined, but others are probably also present.

Genus *Hyolithes* Eichwald, 1840 (type species *H. acutus* Eichwald, 1840).

Hyolithes obesus Holm, 1893.

1893. *Hyolithus obesus* nov. sp. — Holm, Hyolithidæ och Conularidæ, p. 75, pl. 5, figs. 34—39. (Description, figs. of shells and cross sections.)

Remarks: — Only compressed specimens are known. The Rogaland material agrees well with Holm's description of compressed specimens in Sweden, having an angle of divergence of about 30°. One individual shows the convex dorsal lip. Little is seen of the ornament. One specimen has an angle of divergence of 23°, thus approaching the angle (13°) of the species *H. ölandicus* Holm, 1893, which is rather similar to *H. obesus* in other respects.

Occurrence: — Norway (Rogaland), Sweden.

Genus *Orthotheca* Novak, 1886 (type species: *O. intermedia* Novak, 1886).

Orthotheca teretiuscula (Linnarsson, 1877).

1877. *Hyolithus teretiusculus* n. sp. — Linnarsson, Om faunaen i lagren med Parad. öland., p. 22 (373), pl. 2 (15), fig. 11. (Description, figs. of shell, cross section, and ornament.)

1893. *Hyolithus (Orthotheca) teretiusculus* Linnarsson — Holm, Hyolithidæ och Conularidæ, p. 51, pl. 1, figs. 21—24. (Description, figs. of shell and cross sections.)

Remarks: — Among the numerous, more or less badly preserved hyolithids, some show a striation like that characteristic of this species. The angle of divergence is about 10°, which is somewhat more than in the Swedish material (6°—7°).

Occurrence: — Norway (Rogaland), Sweden.

PORIFERA

Order **Hexactinellida** O. Schmidt (Triaxonia F. E. Schultze).
Family **Protospongidae** Hinde.
Genus *Protospongia* Salter, 1864 (type species: *P. fenestrata* Salter, 1864).

Protospongia? sp. — Pl. 2, fig. 8.

Remarks: — The skeleton is not preserved, but great masses of spicules occur. The rays are slender, extending out at right angles to each other to form a cross in the bedding plane. There is also a central axis. In specimens with counterpiece both a downward-pointing and an upward-pointing ray may be seen. The spicules vary in size. The largest spicules have up to 8 mm long rays, but they are only 0.1 mm wide. The spicules seem to be round in cross section and do not oppear swollen at their bases. They resemble those of *Protospongia fenestrata,* but differ in being hexactinellid.

Family **Chancelloridae** Walcott, 1920.
Genus *Chancelloria* Walcott, 1920 (type species: *C. eros* Walcott, 1920).

Chancelloria sp. — Pl. 2, fig. 9.

Remarks: — Only scattered spicules are known. They consist of a central disc with 4, 6 or 7 "horizontal" rays, and possibly a vertical ray. The "horizontal" rays slope down like frames of an umbrella. A six-rayed spicule, c. 1.7 mm in diameter from the tips of the rays, has the following proportions; body of spicule 0.5 mm, central disc or node 0.25 mm, length of ray from where it joins the body, 0.6 mm. The shape of their spicules and their varying number of rays agree well with *Chancelloria,* as described by Walcott (1920, p. 372) from the Middle Cambrian of North America. Some spicules even appear to have a round cavity at the base of each transverse ray, as described in *C. drusila* Walcott (1920, p. 331). *Chancelloria* has been described from Spain (R. & E. Richter, 1940) in the *Saukianda* Beds (probably uppermost Lower Cambrian, cf. Henningsmoen, 1951), and may probably occur in the Middle Cambrian of Manchuria (cf. R. & E. Richter, 1940, p. 53).

Chancelloria sp. has not been found on the same bedding surfaces as *Protospongia*? sp.

PROBLEMATICA

Different types of problematica are present in the Rogaland Rogaland material. Some are flat, filled with an earthy substance showing no structures. These fossils usually have the outline of twigs, worms and sausages.

Another type of problematica (Pl. 2, fig. 7) is represented by a few specimens. They are ovate in outline, the longest diameter varying from 0.7 to 4 cm. A number (c. 6) of cracks or ridges radiate from the center. Some fine radiating ridges may represent an original structure, but rather similar, not radiating structures appear to be of a secondary origin. Quite similar problematica have been found in Middle Cambrian shale from Krekling in SE Norway. Here they show a transition over to forms with no radiating cracks. The latter forms appear to be better preserved, and though the general outline is ovate, it has four rather shallow indentations, dividing the outline into four lobes. A not too well preserved specimen (not showing the natural outline) has been figured by Brøgger (1878, p. IV, fig. 18). These problematica remind one somewhat of an archaeocyathid described by Bornemann (1886, p. 57, pl. 11, figs. 8 d, 8 e) as *Archaeocyathus bilobus* from the Lower Cambrian of Sardinia. However, the true nature of the problematica is questionary.

DISCUSSION OF FAUNA

The fossils are from several collecting grounds, and although these are quite near together, they do not all belong to the same level. Most of the forms occur associated, two or more together. However, *Perenopsis fallax,* the articulate brachiopod, *Protospongia*? sp., and the round problematica have only been found isolated.

The following species are common to Rogaland and the type area (Öland, Sweden) of the *Paradoxides oelandicus* fauna: *Paradoxides oelandicus, P. pinus, Peronopsis fallax, Hyolithes obesus, Orthotheca teretiuscula, Acrothele (Redlichella) granulata,* and *Acrotreta socialis.* Only *Perenopsis fallax* and the two brachiopods are also known to occur in beds younger than the *Paradoxides oelandicus* stage. None of them have been found in older beds. The Rogaland fauna is thus a typical *oelandicus* fauna. The *Paradoxides oelandicus* stage has been divided into two zones (Westergård, 1936); a lower zone with *Paradoxides insularis,* and an upper zone with *P. pinus.* The find of *P. pinus* shows that the upper zone is present in Rogaland. The other fossils found are either known to occur in both zones, or are not recorded previously from the *P. oelandicus* stage. As *P. insularis* has not been found in Rogaland, it is doubtful whether also the lower zone is present.

Paradoxides oelandicus faunas were earlier known in Norway only from Ringsaker in the Mjøsa district (Brøgger, 1882; Strand, 1929) and Hadeland (Strand, 1929, 1948). The localities at Ringsaker are in the allochthonous series of the area of Caledonian overthrusts (Skjeseth, 1952), and so is that of Hadeland, where the beds are interpreted as belonging to a nappe (Strand, 1948). The occurrence in Rogaland is thus the only one known in autochthonous beds in Norway. The *Paradoxides oelandicus* beds (lcα) are not known from the parautochthonous beds in the Mjøsa district, or in Hadeland (cf. Strand, 1948), or father south in the Oslo region. Probably these beds were never deposited in the areas with parautochthonous and autochthonous beds in the Oslo region. In these areas the basal Cambrian appears to be of *Paradoxides paradoxissimus* age (lcγ) or later. Cores from diamond drillings in the Skien-Langesund district reveal that the upper part of the basal sandstone intercalates with alum shale containing fossils of the *P. paradoxissimus* stage. The sandstone as a whole may probably belong to this stage.

The *Paradoxides oelandicus* stage is known from many localities in Sweden (cf. Westergård, 1936). No true *P. oelandicus* faunas have been found outside Scandinavia. As stated by Lake (1935, p. 224), the British specimens which were suspected by Cobbold (1934) to belong to *P. oelandicus* or *P. pinus* are quite insufficient to determine the species. Faunas probably contemporaneous with the *P. oelandicus* fauna have been tabulated by Cobbold & Pocock (1934, pl. 39).

When the known occurrences of the *P. oelandicus* fauna are plotted on a map of Scandinavia (text fig. 1), it is seen that the fauna has been found partly in the Caledonian mountain chain area, and partly in an area stretching from Närke to Öland in Sweden. In an area from Mjøsa (parautochthonous series) across Oslo to Scania and Bornholm the *P. oelandicus* beds are missing in the known sections where they might be expected, probably indicating a land area at the *P. oelandicus* time. This is rather interesting, as this Oslo-Scania area later in the Cambrian, and at times in the Ordovician appears to have been deeper below sea-level than other areas in southern Scandinavia outside the Caledonian geosyncline. The Oslo-Scania land area was probably bordered to the east by a shallow sea, to the north by the Caledonian geosyncline, and to the west probably united with another land area. This area (covering parts of present southern Norway) may have been present south of the Caledonian geosyncline during parts or the whole of the Cambro-Silurian time.

List of fossils from the
***Paradoxides oelandicus* stage (1cα) in Norway**[1]

	Rogaland	Hadeland	Ringsaker
Trilobitae			
Paradoxides oelandicus Sjögren	+	cf.	+
» pinus Westergård	+	cf.	
» torelli Westergård			+
» sp.		+	
Ptychoparia anderseni sp. n.	+		
Solenopleura cristata Linnarsson			+
Bailiella emarginata (Linnarsson)[2]			+
Ptychagnostus (Triplagnostus) praecurrens (Westergård)			+
Brachiopoda			
Orthoid brachiopod	+		
Lingulella sp.	+		
Lingulella ferruginea Salter			+
Acrothele (Redlichella) granulata (Linnarsson)	+		+
Acrotreta socialis v. Seebach	+		+
Hyolitha			
Hyolithes obesus Holm	+		
Orthotheca teretiuscula (Linnarsson)	+		
Porifera			
Protospongia sp.	+		
Chancelloria sp.	+		
Problematica	+		

[1] Corresponding list for Sweden: Westergård, 1936 (pp. 52—63).
[2] Not previously recorded from Norway.

Fig. 1. *Paradoxides oelandicus* stage in Scandinavia. — *1* Rogaland, *2—7* Oslo region: *2* Skien-Langesund district, *3* Oslo district, *4—5* Hadeland, *6—7* Mjøsa district (*6* Ringsaker), *8—9* S. Jämtland, *10—11* N. Jämtland and Ångermanland, *12* Lappland, *13* Närke, *14* Östergötland, *15* Västergötland, *16* Gotland, *17* Öland, *18* Scania, *19* Bornholm.

■ Allochthonous.
● Autochthonous and parautochthonous.
○ Missing in the autochthonous and parautochthonous series.

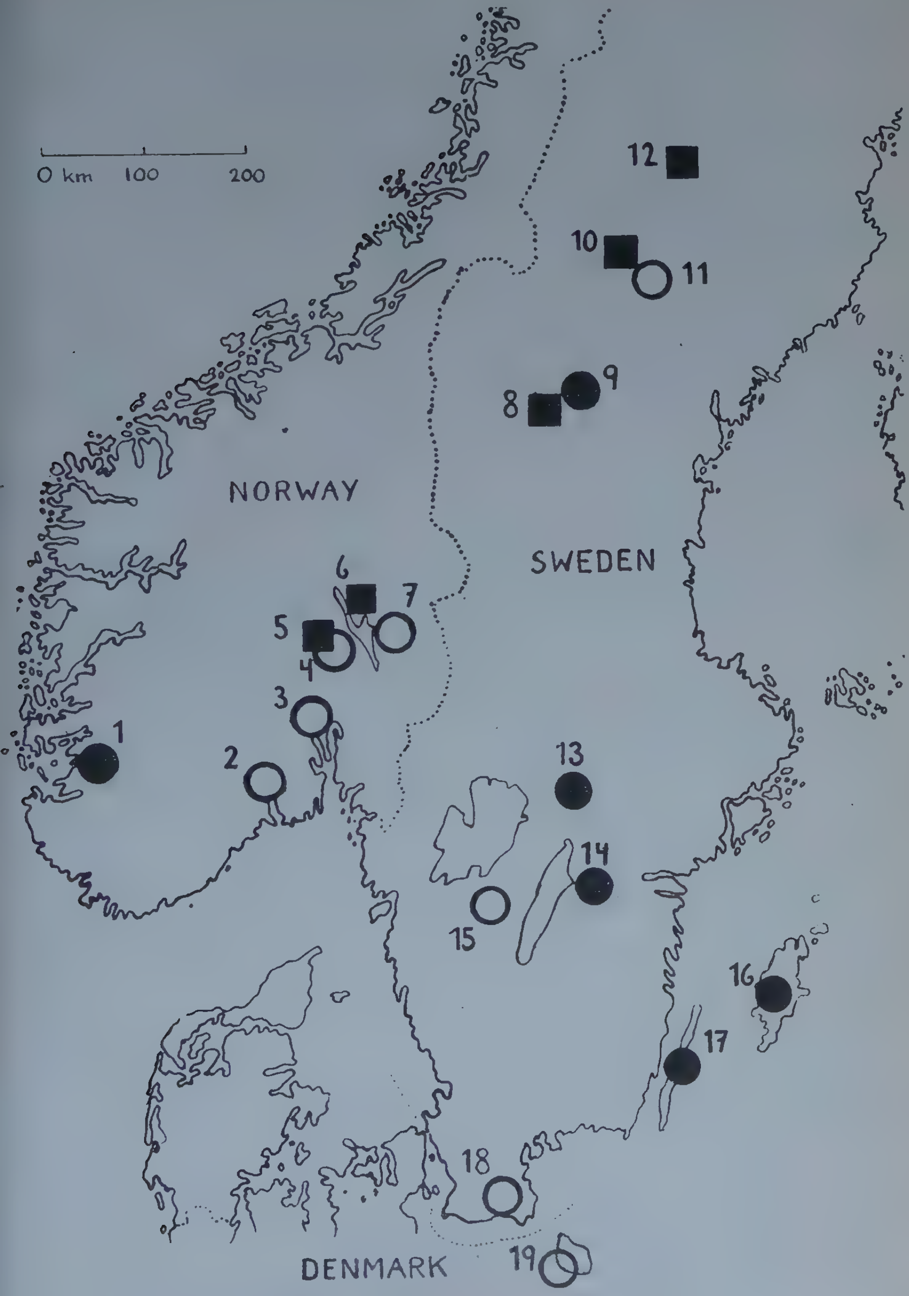

0 km 100 200
NORWAY
SWEDEN
DENMARK
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

Fig 1,

KAMBRISKE FOSSILER FRA ROGALAND

Under geologisk kartlegningsarbeide i Rogaland sommeren 1949 fant cand. real. Bjørn Andersen en forstening, trilobitten *Paradoxides pinus,* og etter hvert flere andre fossiler. Det er første gang fossiler fra kambrium-tiden er funnet på vestkysten av Norge. Foruten Bjørn Andersen har også konservator Holger Holgersen (Stavanger Museum), herr Tor Ritland og cand. real. Nils Spjeldnæs (Paleontologisk Institutt, Oslo) samlet inn fossiler samme sted.

Fossilene fins i mørk, grå-streket (alunskifer-lignende) skifer i en fjellvegg og i uren under, mindre enn 1 km vest for gården Ritland i Hjelmeland herred ved Jøsenfjorden. Det er funnet forstenede trilobitter, brachiopoder, hyolithider, svampe-nåler og usikre forsteninger (se fossil-liste s. 26). En hittil ukjent trilobitt-art, *Ptychoparia anderseni* sp. n., er blitt kalt opp etter finneren av fossil-finnestedet.

Fossilene viser at lagene de ligger i, ble avsatt i havet i tidlig mellom-kambrisk tid. I Norge var disse lagene (*Paradoxides oelandicus*-lagene = lcα) tidligere bare kjent fra Hadeland og Ringsaker. Lagene ble avsatt på bunnen av et stort innsynknings-område (den kaledonske geosynklinal) som bl. a. strakte seg fra Skottland over Skandinavia til Svalbard. I de geologiske tidene nærmest etter kambrium dannet det seg en fjellkjede (den kaledonske fjellkjede) i det samme området, med overskjøvne og foldede fjellmasser. På Hadeland og Ringsaker er lcα-lagene bare kjent fra slikt overskjøvet (alloktont) fjell, og man vet derfor ikke nøyaktig hvor de opprinnelig ble avsatt. Ved Ritland finnes fossilene også i et område med overskjøvne lag, men er funnet under disse, i stedegne (autoktone) lag.

Et kart s. 27 viser de kjente forekomster av lcα-lagene i Skandinavia. Lagene er ikke kjent i de parautoktone (foldede, dvs. litt forskjøvne) og autoktone lagene i Oslo-feltet, og mangler også i lagrekken flere steder i Sverige. Det ser ut som om en landmasse strakte seg fra Mjøsa til Skåne og Bornholm i lcα-tiden. Mot nord var dette Oslo-Skåne-landet begrenset av den kaledonske geosynklinal, mot øst av et grunnere havområde som bl. a. dekket Närke og Öland. Mot vest var Oslo-Skåne-landet antagelig sammenhengende med et annet land-område, som antagelig fantes syd for geosynklinalen, i det minste tidvis under hele kambro-silur-tiden, mens Oslo-Skåne-landet allerede senere i mellom-kambrisk tid sank under havet.

Paleontologisk Museum, Oslo
10. mai 1951.

REFERENCES

Angelin, N. P., 1851—54: Palaeontologia Scandinavica. Pars I. Crustacea formationis transitionis. Pp. I—IX, 1—24, 21—92, pls. I—XLI. Holmiae.

Beecher, C. E., 1891: Development of the Brachiopoda. — Amer. Jour. Sci., ser. 3, *41,* pp. 343—357. New Haven.

Beyrich, E., 1845: Über einige böhmische Trilobiten. — Berlin.

Bornemann, J. G., 1886: Die Versteinerungen des Cambrischen Schichtensystems der Insel Sardinien. — Nova acta der Ksl. Leop.-Carol. Deutschen Akad. der Naturforscher, *51,* 1, pp. 1—147, pls. I—XXXIII. Halle.

Broch, O. A., F. Isachsen, O. Isberg & T. Strand, 1940: Bidrag til Skudenessedimentenes geologi. — Norges geol. unders. 155, pp. 1—41. Oslo.

Brøgger, W. C., 1878: Om paradoxidesskifrene ved Krekling. —Nyt Mag. for Naturvid., *24,* 1, pp. 18—88, pls. I—VI. Kristiania (= Oslo).

— 1882: Paradoxides ölandicus-nivået ved Ringsaker i Norge. — Geol. För. Stockholm Förhandl., *6,* 4, pp. 143—148, pl. 8. Stockholm.

Brongniart, A., 1882: Histoire naturelle des crustacés fossiles. Les trilobites. Paris.

Cobbold, E. S., & R. W. Pocock, 1934: The Cambrian area of Rushton (Shropshire). — Philosoph. Trans. Roy. Soc. London, ser. B, *223,* pp. 305—409, pls 38—45. London.

Corda, A. J. C., in I. Hawle & A. J. C. Corda, 1847: Prodrom einer Monographie der böhmischen Trilobiten. — Abh. böhm. Gesell. Wiss., *5,* pp. 129—292, pls. I—VII. Prag.

Dalman, J. W., 1827: Om palæaderna eller de så kallade trilobiterna. — Kongl. Vetensk. Acad. Handl. 1826, pp. 1—109, pls. I—VI. Stockholm.

Eichwald, E., 1840: Ueber das silurische Schichtensystem in Ehstland. — Zeit. für Natur- und Heilkunde, 1—2. St. Petersburg.

Emmrich, H. F., 1839: De Trilobitis. Dissertatio petrefactologica. — Berlin.

Goldschmidt, V. M., 1925: Ueber fossilführende untercambrische Basalablagerungen bei Ustaoset. — Fennia, *45,* 1, pp. 3—11. Helsingfors.

Hedström, H., 1923: Remarks on some fossils from the diamond boring at the Visby Cement Factory. — Sveriges geol. unders., ser. C., *314,* pp. 1—26, pls. I—II. Stockholm.

Henningsmoen, G., 1951: Remarks on the classification of trilobites. — Norsk geol. tidsskr., *29,* pp. 174—217. Oslo.

Holm, G., 1893: Sveriges kambrisk-siluriska Hyolithidæ och Conularidæ. — Sveriges geol. unders., ser. C, 112, pp. 1—172, pls. 1—6. Stockholm.

Howell, B. F., 1933: The classification of the trilobite subfamily, Centropleurinae. — Medd. fra Dansk Geol. Foren., *8,* 3, pp. 215—219. København.

King, W., 1846. Remarks on certain genera belonging to the class Palliobranchiata. — Ann. & Mag. Natur. Hist., *18,* pp. 26—42. London.

Kutorga, S. S., 1848: Die Brachiopoden der Familie Siphonotretæ. — Verhandl. russ.-kaiser. mineral. Gesell. St. Petersburg 1847, No. 12, pp. 250—286. St. Petersburg.

Lake, P., 1931: A monograph of the British Cambrian trilobites. Part VI, pp. 121—148, pls. XV—XVIII. — Palæontogr. Soc. 1929. London.

— 1932: Idem. Part VII, pp. 149—172, pls. XIX—XXII. — Idem. 1930. London.

— 1935: Idem. Part IX, pp. 197—224, pls. XXVI—XXXI. — Idem. 1934. London.

Linnarsson, J. G. O., 1869: Om Vestergötlands cambriska och siluriska aflagringar. — Kongl. Svenska Vetensk.-Akad. Handl., *8*, 2, pp. 1—89, pls. I—II. Stockholm.

— 1876: On the Brachiopoda of the Paradoxides Beds of Sweden. — Bihang till Kongl. Svenska Vetensk.-Akad. Handl., *3*, 12, pp. 1—34, pls. I—IV. Stockholm.

— 1877. Om faunaen i lagren med *Paradoxides œlandicus*. — Geol. Fören. Stockholm Förhandl., *3*, pp. 352—375, pls. 14—15. (Also as Sveriges geol. unders., ser. C, no. 22.) Stockholm.

Matthew, G. F., 1887: Illustrations of the St. John group. 4. — Proc. & Trans. Roy. Soc. Canada, *5*, pp. 115—166, pls. I—III. Montreal.

M'Coy, F., 1849: On the classification of some British fossil Crustacea. — Ann. & Mag. Natur. Hist., ser. 2, *4*, pp. 161—279, 330—335, 392—414. London.

Novak, O., 1891: Revision der Palaeozoischen Hyolithiden Böhmens. — Abhandl. k. böhm. Gesell. Wiss., ser. 7, *4*, pp. 1—49, pls. I—VI. Prag.

Poulsen, C., 1942: Nogle hidtil ukendte Fossiler fra Bornholms Exsulanskalk. — Medd. fra Dansk Geol. Foren., *10*, pp. 212—235 (1 pl.). København.

Resser, C. E., 1939: The Spence Shale and its fauna. — Smithsonian Misc. Coll., *97*, 12, pp. 1—29, pls. 1—6. City of Washington.

Richter, R., 1932: Crustacea (Paläontologie). — Handwörterbuch der Naturwiss., 2nd. ed., pp. 840—863. Jena.

Richter, R. & E., 1940: Die Saukianda-Stufe von Andalusien, eine främde Fauna im europäischen Ober-Kambrium. — Abhandl. senckenberg. naturf. Gesell., *450*, pp. 1—88, pls. 1—5. Frankfurt a. M.

Salter, J. W., 1864: A Monograph of British Trilobites. — Pp. 1—244, pls. 1—30. Palæontogr. Soc. London.

— 1866: On the fossils of North Wales. — Mem. Geol. Survey, *3*, 1866, appendix, pp. 239—381. London.

Schuchert, C., 1896: Brachiopoda. In text-book of paleontology by Zittel and Eastman, *1*, pp. 291—343.

Seebach, K. von, 1865: Beiträge zur Geologie der Insel Bornholm. — Zeit. deutsch. geol. Gesell., *17*, 2, pp. 338—347. Berlin.

Sjögren, A., 1872: Om några försteningar i Ölands Kambriske lager. — Geol. Fören. Stockholm Förhandl., *1*, pp. 67—80, pl. 5. Stockholm.

Skjeseth, S., 1952: On the lower Didymograptus zone (3 B) at Ringsaker, and contemporaneous deposits in Scandinavia. — Norsk geol. tidsskr., *30*.

Størmer, L., 1925: On a Lower Cambrian fauna at Ustaoset in Norway. — Fennia, *45*, 1, pp. 12—22, pls. I—II. Helsingfors.

Strand, T., 1929: The Cambrian beds of the Mjøsen district in Norway. — Norsk geol. tidsskr., *10,* 3—4, pp. 307—365, pls. I—II. Oslo.

— 1948: On the Middle Cambrian of Hadeland (Oslo region, Southern Norway). — Norsk geol. tidsskr., *27,* pp. 89—96. Oslo.

Swinnerton, H. H., 1915: Suggestion for a revised classification of trilobites. — Geol. Mag., ser. 6, *2,* pp. 487—496, 538—545. London.

Wahlenberg, G., 1821: Petrificata Telluris Svecana. — Acta Soc. Regiae Sci. *8.* Stockholm.

Walcott, C. D., 1902: *Cambrian Brachiopoda: Acrotreta; Linnarsonella; Obolus;* with description of new species. — Proc. U. S. Nat. Mus., *25,* pp. 757—612.

— 1908: Cambrian Brachiopoda; description of new genera and species. — Smithsonian Misc. Coll., *53,* 3, pp. 53—137, pls. 7—10. City of Washington.

— 1908 b: Cambrian Geology and Paleontology. No. 4. Classification and terminology of Cambrian Brachiopoda. — Smithsonian Misc. Coll., *53,* pp. 138—165. City of Washington.

— 1912: Cambrian Brachiopoda. — Monographs U. S. Geol. Survey, *51,* pp. 1—872, pls. I—CIV. City of Washington.

— 1920: Cambrian Geology and Paleontology, IV. No. 6. Middle Cambrian Spongiae. — Smithsonian Misc. Coll., *67,* 6, pp. 261—364, pls. 60—90. City of Washington.

Wenz, W., 1938: Gastropoda. Teil I. — Handbuch der Paläozoologie, *6,* 1 (edit.: O. H. Schindewolf). — Berlin.

Westergård, A. H., 1936: Paradoxides œlandicus Beds of Öland. — Sveriges geol. unders., ser. C, *394,* pp. 1—66, pls. I—XII. Stockholm.

— 1946: Agnostidea of the Middle Cambrian of Sweden. — Idem. *477,* pp. 1—140, pls. 1—16. Stockholm.

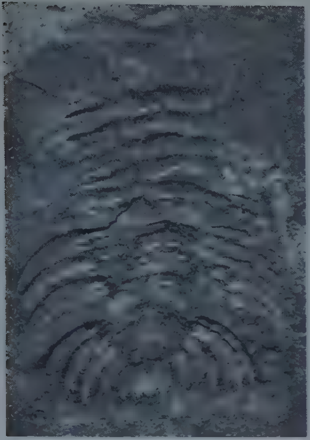
PLATE 1

The photographs are not retouched. The specimen in fig. 1 was photographed immersed in alcohol; the specimens in figs. 2—4 were whitened with ammonium chloride, Photographer: Miss B. Mauritz.

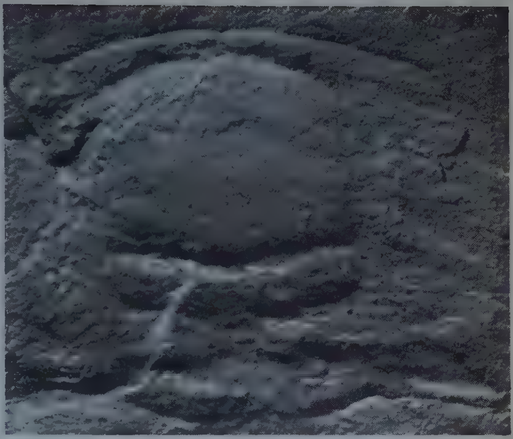
PMO. = Paleontologisk Museum, Oslo.

SM. = Stavanger Museum.

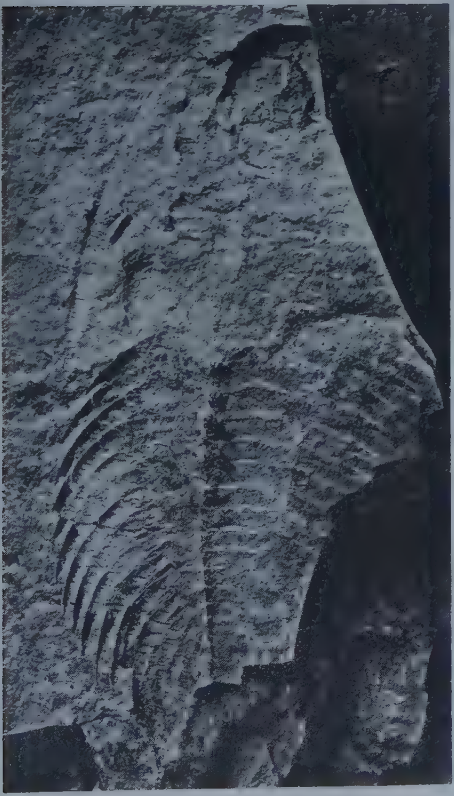
Fig. 1. *Paradoxides oelandicus* Sjögren. Pygidium and thorax. SM. 1951/52. × 1.7.
2. *Paradoxides* sp., probably of the *oelandicus* group. Cranidium. SM. 1951/52. — × 1.7.
3. *Paradoxides pinus* Westergård. Disconnected dorsal shield. PMO. 66399. — × 1.6.
4. Counterpiece of specimen in fig. 3. — PMO. 66400. — × 1.6.



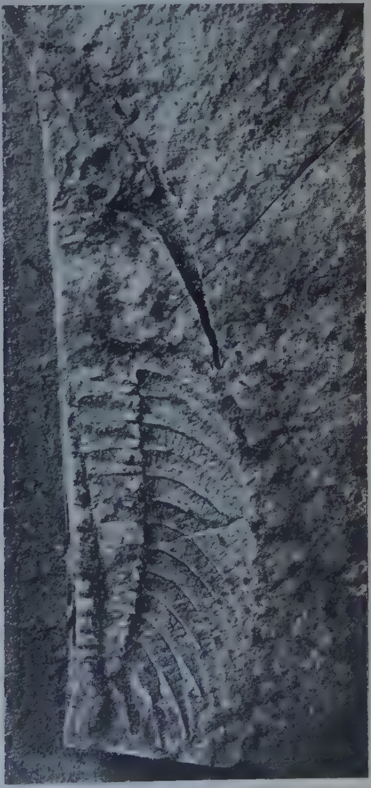
1



2



3



4

PLATE 2

The photographs are not retouched. All specimens were whitened with ammonium chloride before being photographed.

Photographer: Miss B. Mauritz.

PMO. = Paleontologisk Museum, Oslo.

Fig. 1. *Ptychoparia anderseni* sp. n. Holotype. External mould of cephalon and thorax. PMO. 66300. × 2.7.

2. *Ptychoparia anderseni* sp. n. Artificial cast of the holotype (fig. 1). — × 3.

3. *Acrothele (Redlichella) granulata* Linnarsson. Ventral valve. PMO. 66391. — × 5.

4. *Lingulella sp. Ventral valve.* PMO. 66392. — 3.7.

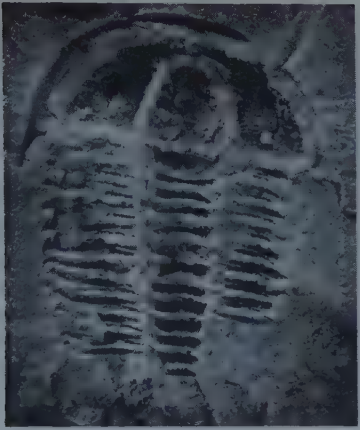
5. *Peronopsis fallax* (Linnarsson). Cephalon and pygidium. PMO. 66393. — × 10.

6. Orthoid brachiopod. PMO. 66394. — × 4.

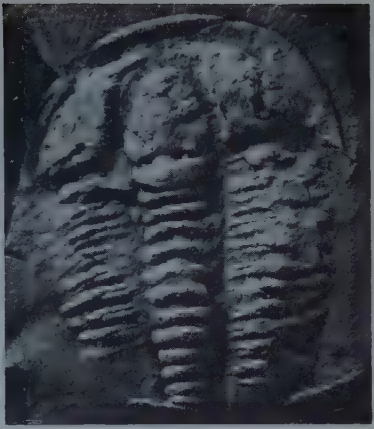
7. Problematicum. PMO. 66395. — × 2.3.

8. *Protospongia?* sp. Spicule. PMO. 66396. — × 10.

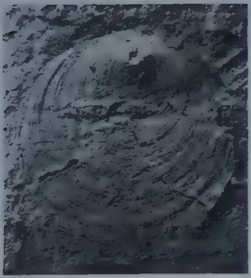
9. *Chancelloria* sp. Spicule. PMO. 66397. — × 10.



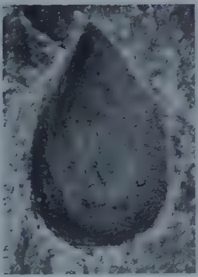
1



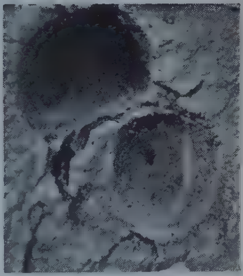
2



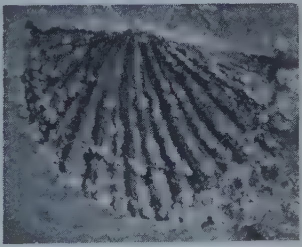
3



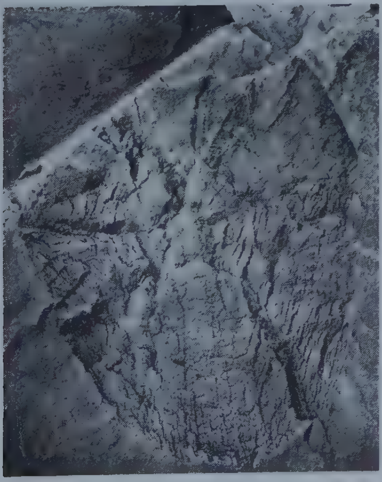
4



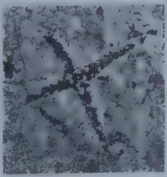
5



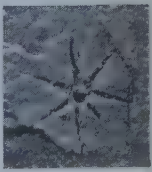
6



7



8



9

METAMORPHOSED DOLERITES IN THE GNEISS AREA OF SUNNMØRE ON THE WEST COAST OF SOUTHERN NORWAY

BY

TORE GJELSVIK

Contents.

- Abstract 33
- Introduction 34
  - Acknowledgement 34
  - Geographical relations 34
  - Earlier investigations in the area 35
- General field relations 36
  - Geological setting 36
  - Distribution of dolerites 39
  - Field relations of dolerites 40
- Petrography 41
  - The dolerites 41
    - Mineral constituents 41
    - Common features 42
    - Dolerite varieties 42
    - Metamorphism 48
    - Dolerite dikes 58
  - Granitic dikes and pegmatite in dolerites 59
    - Leuco-granodioritic dikes 59
    - Granite pegmatite 59
  - Dolerites of uncertain origin 61
  - Additional remarks on the mineralogy of dolerites 63
    - On the methods of mineral identification of extrusive and hypabyssal rocks 63
    - Methods used in mineral identification in this paper 69
    - Primary minerals 70
    - Secondary minerals 76
- Chemical composition 79
  - Bulk analyses 79
  - Trace elements 84
- Petrological interpretation 86
  - Igneous phase 86
    - Age relations of minerals 86
    - Mechanism of intrusion 87
    - Temperature of crystallization 88
    - Reaction between magma and wallrock 89
    - Differentiation of magma 90
    - Genesis of the titaniferous iron ores of dolerites 96

Metamorphic phase 98
Exsolution 98
The coronas 100
Other metamorphic phenomena 103
Metasomatism of dolerites 104
Metamorphic mineral facies 105
Comparison with other dolerite provinces 107
Geochemical aspect 107
Comparison with the hyperites of SE Norway 112
Classification and nomenclature 115
Age of dolerite intrusion 118
The consanguinity of the Sunnmøre dolerites and eclogites 123
Summary of conclusions 125

Illustrations.

Text figures.

Fig. 1. Location and geological setting of the investigated area 37
» 2. Distribution of dolerites within Sunnmøre 39
» 3. Replacement and coronas of olivine 50
» 4. Amphibolitization of augite edges 51
» 5. Coronas and concentric alteration of hypersthene 52
» 6. Coronas of augite and hypersthene 53
» 7. Coronas in olivine-free dolerites 54
» 8. Advanced metamorphism of olivine dolerite 56
» 9. End stage of metamorphism of dolerites 57
» 10. Alteration of dolerite along granite pegmatite 61
» 11. Optical properties of olivines 73
» 12. Variation diagram of dolerites 83
» 13. Ore concentrations of dolerites 97

Plate figures.

Fig. 1. Dolerite dike, Ellingsøy
» 2. Texture of olivine dolerite
» 3. Coarsegrained dolerite
» 4. Weathered surface of olivine dolerite
» 5. Idiomorphic olivine crystals
» 6. Pseudoporphyric hypersthene crystal
» 7. Intergrowths of augite and hyperstene
» 8. —»— —»—
» 9. Dolerite pegmatite
» 10. Olivine coronas
» 11. Secondary minerals in plagioclase
» 12. Replacement of olivine, early stage
» 13. —»— later stage
» 14. Amphibolitization of augite edges
» 15. Coronas and concentric alteration of hypersthene
» 16. Coronas of augite and hypersthene
» 17. Advanced metamorphism of dolerite
» 18. Intergrowth of plagioclase and diopside
» 19. Replacement of iron ores

Fig. 20. End stage of metamorphism of dolerites
» 21. Finegrained dike in dolerite, Haramsgrend
» 22. Granite pegmatite in dolerite, Ellingsøy
» 23. —»— —»—
» 24. —»— —»—
» 25. Porphyric olivine dolerite. Uncertain locality
» 26. Clouded plagioclase
» 27. "Reaction" rims of orthoclase
» 28. Olivine crystals imbedded in augite

Tables.

Table 1. Optical properties of olivines 72
» 2. Analysis of spinel 76
» 3. Chemical analyses of Sunnmøre dolerites 79
» 4. Normes and modes —»— 80
» 5. Modes of dolerites not chemically analyzed 81
» 6. Trace elements of Sunnmøre and Gudbrandsdal dolerites 85
» 7. Calculation of the differentiation of dolerites 92
» 8. Average chemical composition of various basaltic provinces .. 108
» 9. Average chemical composition of basaltic provinces of Norway and Sweden 109
» 10. Trace elements of various basaltic provinces 111
» 11. Comparison between dolerites of Sunmøre and hyperites of SE Norway 113

Abstract. Dolerites of olivine basaltic composition occur in the northern gneiss area of Sunnmøre (also farther N and NE). Two main types are found; both rich in plagioclase, namely subophitic olivine dolerites, fine to medium grained, occasionally with (optically anomalous) hypersthene, and subdoleritic, olivine-free dolerites, medium to coarse grained, usually carrying small amounts of (optically normal) hypersthene.

The shape of the dolerite is invariably that of a symmetrical laccolith, concordantly enveloped by gneiss. Although a few minor, transgressive structures are found, neither crosscutting feeding channels nor stoped blocks of the wallrock are observed.

Chemically, the dolerites are characterized by high Al, relatively low Ca, and very low H_2O. Of the trace elements, V is abundant, while Cr is practically absent.

After consolidation, large-scaled reactions between the pyrogenic minerals took place, and a series of secondary minerals were formed: bronzite, diopside, garnet, biotite, amphibole, etc., initially in a peculiar corona pattern. The final products of metamorphism are eclogite-like, amphibolitic rocks with crystalloblastic texture.

The primary and secondary stages of the genetic history of the dolerites are discussed. A comparison with other dolerite provinces discloses a rather close similarity with the hyperites of SE Norway and SW Sweden. Finally, the age problem of the intrusion is considered, and the consanguinity of the Sunnmøre dolerites and eclogites is shortly discussed. A summary of the petrological discussions is presented on pp. 125—131.

Introduction.

Acknowledgements.

The author is greatly indebted to Professor, Dr. T. F. W. Barth, Director of the Mineralogical-Geological Museum of the University of Oslo. Dr. Barth has taken a continuous interest in the investigations of Sunnmøre, and has made all facilities of the Museum available for the author.

During the work, the author has profited from many discussions with Dr. Barth and Dr. H. Neumann, and from communication with Dr. E. S. Larsen jr., Professor Emeritus from Harvard University, Cambridge, Mass., U. S. A. The author's expression of sincere gratitude to them does not implicate that they share the responsibility for the views expressed in the paper.

The author has received substantial financial support from "Width Endresens Fond til Fremme av Sunnmøres Næringsliv" and Fondet "Nationalgaven til Chr. Michelsen", and the Royal Norwegian Council for Scientific and Industrial Research.

The following persons are to be thanked for valuable assistance of different kinds:

Professor, Dr. I. Oftedal, Mineralogical Institute of the University of Oslo.
Civil engineers B. Bruun and S. Rutlin, Statens råstofflaboratorium, (chemical and spectrochemical analyses).
Miss B. Mauritz (micro-photography).
Miss B. Bjerknes, Mrs. H. Hjort, and Miss J. Spange (illustrations).
Mr. A. Granli and Mr. E. Fjellet (preparation of thin sections).
Mr. A. Iversen (preparation of polished sections).
Mrs. Fredrik Barth (correction of language).

Geographical relations.

Most of Sunnmøre consists of a rather rugged mountain region between 3000 and 6000 feet a.s. The highest peaks reach 6000 feet, and the mountain plateau gently slopes down to 1000—2000 feet towards the coast. A great number of narrow fjords and valleys are cut deeply and steeply into the mountain region. On the islands and along the coast a low plateau — the strandflat, is formed. The fiords and valleys owe their present shape to the erosion of the great inland ice which covered Scandinavia in Pleistocene time. The moving ice, no doubt, mostly followed old river valleys, and many of the fiords resemble drowned valleys. These old valleys, again, follow the pattern determined by the main structures of the gneisses: east-west strike and transverse fractures. The result of the work of the eroding agents and later organic life is a country of great beauty: blue fiords and green valleys surrounded by rugged mountains, the peaks of which are covered by snow a great part of the year. Some of the most famous fiords of Norway are situated here, the biggest being Nordfjord, Hjørundfjord, Storfjord and Romsdalsfjord.

This beautiful country, however, also gives the scientist trying to investigate the geology of the area, a very exhausting and difficult job. Many of the mountainslopes are almost vertical, at least from a practical point of view. The high mountains also bring about rather heavy rainfalls of the humid winds of the Atlantic Ocean, even at summertime long spells of dry weather are rare. The plentiful rain, too, gives rise to a rather luxuriant vegetation, which covers otherwise good exposures of rocks. Excellent exposures are developed along the shores and glaciers, or by new roadcuts. The high mountain region offers no possibilities for human activities, except for some short summer months. Only the strandflat, the lower valleys and some parts of the less steep mountainsides along the fiords, have been settled by people. Fishing and farming are the main industries.

Earlier investigations in the area.

The gneiss area of Sunnmøre had not been subjected to systematic geological investigation until the present author started his work in 1942. Some parts of it, the islands south of Ålesund, and the area between Hjørundfjord and Nordfjord, were investigated and mapped in a preliminary way by H. H. Reusch (1877). The dunites of Sunnmøre and Nordfjord were described by J. H. L. Vogt (1883), Brøgger (1879) and Reusch (1883), and the eclogites within the same area were investigated by Eskola (1921). C. Bugge surveyed the crystalline limestones occurring along the outer coast (1905) and discovered the Caledonian greenschists on the islands outside Molde in the Romsdalsfjord (1934).

A. Heltzen investigated the rocks around the titaniferous iron ores at Sjøholt, that occur within one of the larger dolerite-bodies.

(Unpublished thesis at The Norwegian Institute of Technology, Trondheim). Finally, a general description of the rocks, and a geological map made by the present author and Chr. C. Gleditsch covering the whole gneiss-area between Nordfjord and Romsdalsfjord, has been published (Gjelsvik 1950). The dolerites are included in the gneiss-groups 1 and 4 of this map, and described as gabbros and olivine gabbros.

General field relations.

Geological setting.

The gneiss area of Møre and Romsdal (the southern part of which is Sunnmøre) is situated WSW (in the strike direction) of the Caledonian Trondheim region (fig. 1 below). Eastward, the gneiss area borders, without discordance, the Caledonian rocks of North Gudbrandsdal. It predominantly consists of grey, coarsegrained, grano-

---

— —	Post-Caledonian faults in eastern Southern Norway.
▤	Effusive } Permian igneous rocks of the Oslo Intrusive } Region
▨	Downtonian-Devonian Old Red deposits of South Norwegian marginal districts. Folded or thrust in post-Orcadian time.
▩	'Valdres Sparagmite' and conglomerate. Synorogenetic, in part contemporaneous with thrust of Jotunheim eruptives.
▧	Thrust masses with quartzitic rocks besides gneiss and granite in the Voss district etc. of western Southern Norway.
⁙	Plutonic igneous rocks of Caledonian or supposed Caledonian age, mainly gabbro, trondhjemite and granite occurring as intrusive or thrust masses in or above Cambro-Silurian schists.
▩	Anorthosite-mangerite rocks tectonically belonging to the above -mentioned group.
■	Cambro-Silurian or probably Cambro-Silurian sedimentary rocks, including, in western and northwestern district, also effusive ones. More or less metamorphic except in Oslo Region and Hyolithus zone.
⁙ ▧ ▨	Highly metamorphic (sparagmite-gneiss etc.) Moderately metamorphic Non-metamorphic or only slightly metamorphic } Sedimentary rocks of Eo-Cambrian or probably Eo-Cambrian age.
□	Basal crystalline complex of relatively central orogenetic districts, including granites of 'bottom-massives' of Nordland. Mainly gneisses and granites (grey and red), also mica and hornblende schists, limestone, besides intermediate and basic igneous rocks.
▧	Occurrence of considerable masses of rocks of the anorthosite-mangerite group in the basal or (Bergen district) supposed basal gneiss complex.
▥	Basal complex of some intermediate districts which largely represent the Rombak anticlinal zone (A of sections). Rocks pre-Sparagmitian or mainly so.
▥	Archean rocks as overthrust masses in Femund and Laksefjord districts.
▥	Pre-Sparagmitian, mostly Archean, basal, complex of foreland and relatively peripheral orogenetic districts. Rocks unaltered during Caledonian deformation.
▦	Anorthosite district south of Stavanger.

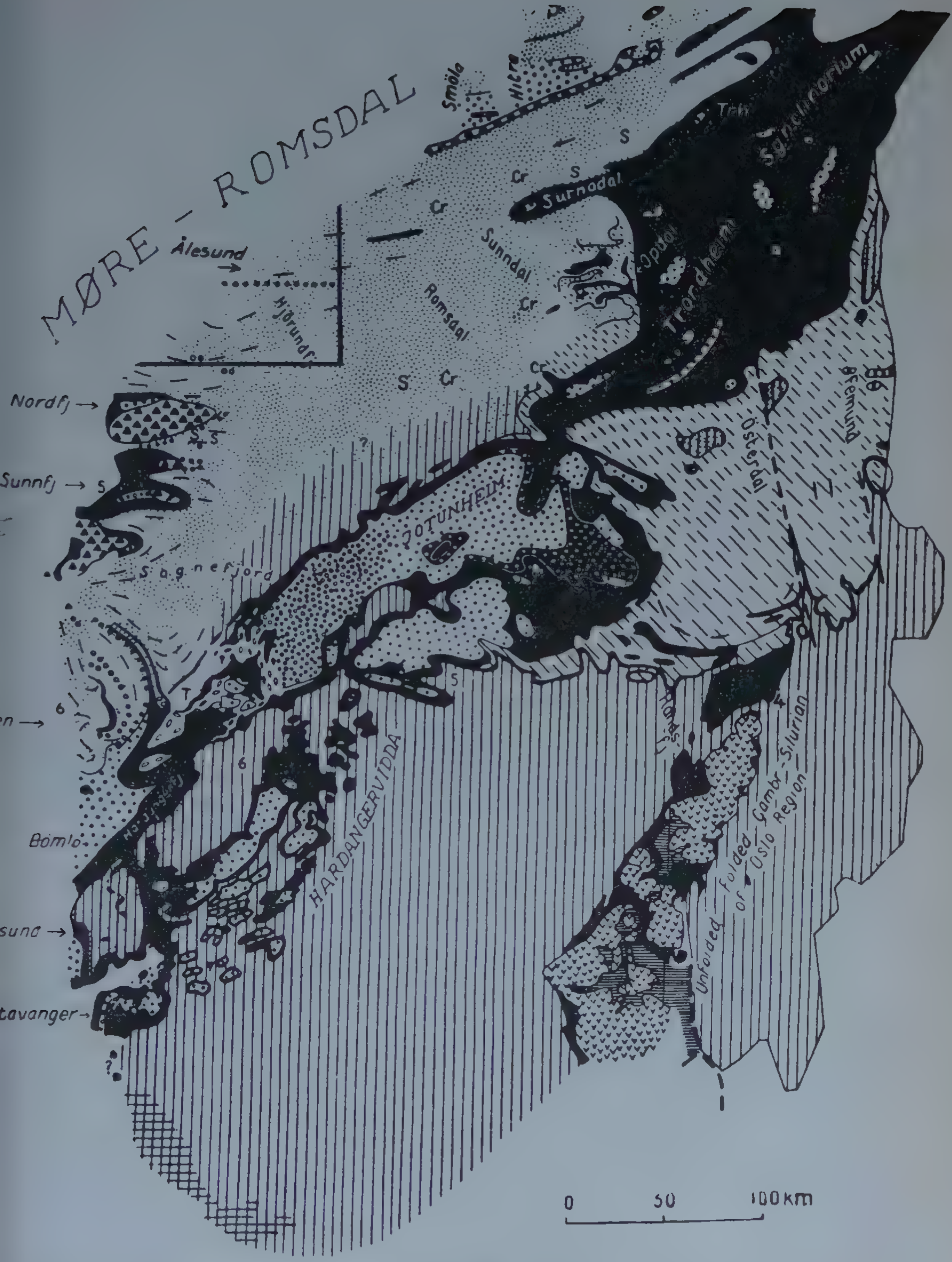


Fig. 1. Location and geological setting of the investigated area. Dotted line indicates the south limit of dolerite distribution. The map is a somewhat simplified part of Holtedahl's map (1944).

dioritic gneisses, with bands, lenses, veins, augen, and pegmatites of granitic (sometimes granodioritic) material. In the granodioritic gneisses the minerals are: quartz, oligoclase (an 20), less amounts of microcline, and biotite, frequently also amphibole. Quartz and microcline are prevailing in the granitic veins. In parts the gneisses are more fine-grained, with less granitic material, and still at other places occur: quartzite, flagstone, micaschist, leptite, etc., mostly fine-grained rocks of unquestionably supracrustal origin. Crystalline limestone with adjacent beds of lime-silicate gneisses are most plentiful along the coast. The rock-forming minerals of the limesilicate gneisses are: oligoclase (an 20—30), amphibole, diopside, red garnet, biotite, epidote, scapolite, calcite and quartz. The rocks of the continuation of the Surnadal syncline comprise greenstone (metamorphosed Støren basalt, mainly consisting of amphibole), other limesilicate- and alumosilicate schists, and some impure, crystalline limestones.

Different monomineralic, mafic or ultramafic rocks, like anorthosite, amphibolite, eclogite and dunite (also saxonite or serpentine) are seen to form concordant lenses in the gneisses. They never show transgressive structures, are usually schistose and thoroughly altered and of small extent. One of the dunite bodies measures 5—6 km in length and 1 km across, but most of them are only a few hundred meters long. The mafic inclusions cover probably less than one per cent of the total area, but are nevertheless conspicuous features of the gneisses in which they occur.

The structures of the rocks show that the whole area has been subjected to intense orogenic movements. In the northern part, large synclines and anticlines, partly overturned, have been exactly located. In the southern part the same conditions prevail, but so far the structural elements have not been worked out in details. In many places the gneisses show minor folds, also. The axes of the large folds, and of most minor ones, are nearly parallel to the consistent E—W strike, and dip 10—20° E. In some parts of Sunnmøre, outside the dolerite-area, minor fold axes striking N or S, are found. Discordant structures, although present, are rare, indicating that most of the rocks have been deformed at considerable depth. Plastic flow structures are frequently seen, but not within the dolerite area.

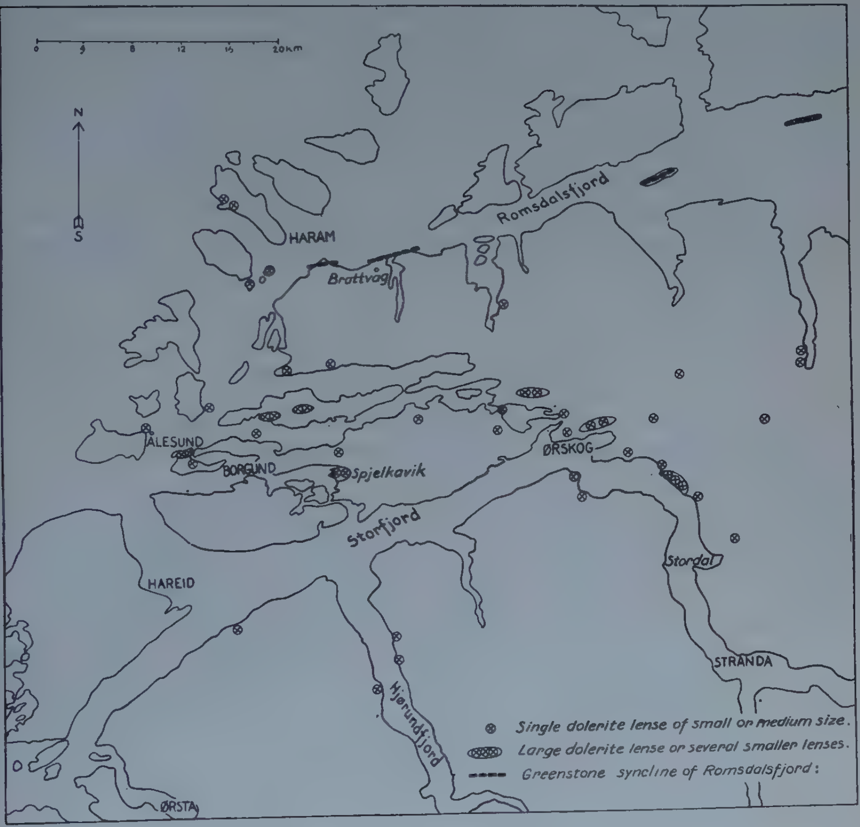

0
4
8
12
16
20km
N
S
HARAM
Brattvåg
Romsdalsfjord
ÅLESUND
BORGUND
Spjelkavik
ØRSKOG
Storfjord
Stordal
HAREID
STRANDA
Hjørundfjord
ØRSTA
⊗ Single dolerite lense of small or medium size.
Large dolerite lense or several smaller lenses.
---- Greenstone syncline of Romsdalsfjord:

Fig. 2. Distribution of dolerites within Sunnmøre.

Distribution of dolerites within Sunnmøre.

Lack of adequate topographic maps makes it impossible to map the different dolerite-bodies within Sunnmøre. On the sketch-map, fig. 2, are indicated the dolerites encountered by the author, and also the source of specimens present in the collections of the Mineralogical-Geological Museum of the University of Oslo. No doubt there are additional occurrences not yet found. The survey made by the author and his co-workers demonstrates that the dolerites are concentrated north of the E—W-line from the mouth of Storfjord, across Stordal and to Åndalsnes (dotted line on the key map, fig. 1, p. 37). It is not impossible, however, that some of the abundant amphibolites and eclogites of the southern part of Sunnmøre, are altered dolerites.

The dolerites have intruded, without any preferance, into different types of gneisses. Nor have the intrusions favored especial stratigraphic units or structural directions, although they are numerous within the wide syncline of Ørskog-Skodje. So far the investigations have not disclosed any systematic distribution of the different dolerite types, either.

Outside Sunnmøre, dolerites of identical types are plentiful in Romsdal and some parts of Nordmøre, one locality is known in the »Vestrand« of Fosen, Trøndelag.

Field relations of dolerites.

The relations of the dolerites are analogous to those of the other mafic rocks imbedded in the gneiss. The shape is invariably a symmetrical laccolith, concordantly enveloped by gneiss. The size of the bodies is variable, from ten feet to one mile or so in length. No feeders or magma channels have been observed. The contact dolerite—gneiss is rarely visible, it is mostly covered by soil, drift, vegetation, seawater or snow. When visible, it is often inaccessible in steep mountain sides. Being a hard and tough rock, the dolerite usually protrudes as ridges or hills in the landscape. Nearly all tunnels of the road between Ålesund and Åndalsnes are cut through dolerite ridges. A good exposure of the contact is found, however, at the cape outside Grimstad on the island Ellingsøy (NE of Ålesund). The cape is accessible at low tide only. A rather large wedge of dolerite penetrates into the gneiss, sending several small apophyses into the gneiss parallel to the strike. Two of the apophyses are connected by a small dike cutting the gneiss structure, (fig. 1, pl. I). The occurrence represents the only known display of transgressive dolerite-structures. Here, as at every other contact observed by the author, the dolerite is completely altered to amphibolite close to the border, and in the dike no primary features are preserved. The width of these alteration-zones varies from a few feet to several meters. In some places, the dolerites are intensely sheared and shattered. The fractures are filled with chlorite, only.

The age relationship between the dolerites and the other mafic rocks embedded in the gneiss has not been established. Contacts between unquestionable dolerite and anorthosite or dunite have not been observed. The mafic inclusions exhibit a zonal distribution in the field. As mentioned above, the dolerites are found in the north part of Sunnmøre, most of the dunites occur in parallel rows, often following limesilicate-gneisses. Eclogite, if defined strictly, especially occurs in the south-western coast area, around the Stad peninsula. Amphibolite and different garnet-bearing mafic lenses (transition-types to eclogite) are found almost any place, but predominantly in the central and inner part of Sunnmøre. Anorthosite lenses are found in the inner fiord area, but are still more frequent in the southern part of Sunnmøre, and in Nordfjord.

Petrography.

The dolerites.

Mineral constituents.

The dolerites of Sunnmøre have been subjected to considerable alteration after solidification, and secondary minerals in many cases are predominant. Every petrologist working with metamorphosed igneous rocks is aware of the difficulties involved in discriminating the primary and secondary minerals, especially the autometamorphic or deuteric products, and the reaction products formed after complete solidification of magma. The author considers it to be most correct to include the deuteric reactions in the igneous phase of rock genesis. Consequently, unless otherwise noted, the term "metamorphic" is used in connection with only truly postmagmatic reactions. In the following description of rock types the igneous and metamorphic features are treated separately. The problems arising from this discrimination will be discussed in the chapter on petrology.

The essential, primary minerals in the dolerites are: plagioclase, olivine, augite, hypersthene, and iron ores. Orthoclase is an accessory mineral in the olivine-bearing dolerites, however in some olivine-free types it is essential. The only primary minerals to be classified as strictly accessory are apatite and spinel.

The common secondary minerals are: plagioclase, diopside, bronzite, biotite, garnet, amphibole, quartz, and iron ore (presumably magnetite). The percentage of the different secondary minerals is determined by the degree and character of metamorphism. Scapolite is found in small quantities in two localities. Allanite, sphene, rutile, zircon, and calcite may be found as odd grains in a few rocks. Chlorite is observed forming tiny, crosscutting veins in some rocks.

Common features.

The dolerites are all holocrystalline. The grainsize varies, but at the selvage it is always fine, and it increases towards the central parts. Plagioclase is by far the most abundant mineral, representing 50 per cent or more of the primary constituents, thus the textures of the rocks are dominated by the typical lath-shaped form of this mineral. The laths form a skeleton, the interstices of which are filled by the other minerals. Neither linear nor planar structures of primary origin are observed. In every thin section of the dolerites studied, the primary features are modified by secondary reactions, typically represented by reaction rims, or coronas. Usually these have formed at the contact between plagioclase and olivine or iron ores. (Brøgger, 1934, p. 7). In the dolerites of Sunnmøre they are, furthermore, present between pyroxenes and plagioclase, and, although less commonly, between the femic minerals and orthoclase, and between two different femic minerals, but are then thinner and less consistent. The coronas are made up of tiny crystals, mostly rodshaped or fibrous, arranged vertically to the border of the femic mineral. Granular corona-minerals have sometimes intergrown with the host mineral, forming a vermicular symplectite, which gives the impression of being radially arranged.

Dolerite varieties.

The variation of the chemical composition of dolerites is not great (cf. table 3, p. 79), nor is the serial range of the isomorphic minerals, as far as it can be deduced from the optical properties. But the relative amounts of the rockforming minerals vary considerably from one rock to another. With the exception of the ore-concentrations, there seem to be only small primary variations within any particular body. The evaluation of this problem is greatly hindered by the frequency of advanced metamorphism, however. Local enrichment of feldspar is sometimes observed, and different slides from a single hand specimen many show considerable variation of the relative amount of olivine and augite. Nevertheless such specimens, as well as the dolerite lense from which they are detached, seem to be rather homogeneous. It can safely be stated that, compared to the difference between the lenses, the variation within any particular dolerite lense is of subordinate importance. (Exception is made only for the ore-concentrations.)

The dolerites consist of two main types, olivine-bearing and olivine-free dolerites. Besides the mineralogical difference, these also show considerable variation in grainsize and texture. The olivine-bearing dolerites have fine to medium grainsize, (felspar laths rarely longer than 3 mm), and the augite grains in adjacent interstices belong to the same crystal (fig. 2, pl. I), (the texture termed subophitic by Krokström (1932 b, p. 199) or diabasic by Kemp (1910, p. 159)). The amount of augite is rarely large enough to form an ophitic texture, in the restricted sense of the term. Genetically, there is no difference between subophitic and ophitic texture. In this paper ophitic is used for both. The olivine-free dolerites are medium to coarse-grained (fig. 3, pl. II) (felspar laths sometimes 1 cm or more), and also relatively broader. Pyroxene is interstitial, but the grains in adjacent interstices rarely belong to the same crystal. In a few cases hypersthene exhibits a tendency towards idiomorphic form, but augite always is anhedral, thus the texture is intergranular, as defined by Evans (cf. Holmes 1918, p. 191) or sub-doleritic according to Krokström (op. cit., p. 191).

Olivine-bearing dolerites.

The most common rock of this type is an ordinary olivine dolerite. Estimated primary composition:

Plagioclase	60—70 %
Olivine	5—20 »
Augite	5—20 »
Accessories	5 »

The chemical composition, mode and norm of olivine dolerite are represented by No. I in tables 3 and 4, pp. 79—80. Nos. II and III represent more altered rocks. More olivine dolerite modes are found in table 5, p. 81. The plagioclase is a slightly zoned labradorite (calcic core), clouded by brown, opaque dust. Olivine, a hyalosiderite, shows no sign of zoning, and is often found in idiomorphic or hypidiomorphic grains. Augite is interstitial to both plagioclase and olivine (fig. 28, pl. XIV). As a rule it is so filled by tiny opaque inclusions as to look opaque itself, and may easily be confused with iron ore (fig. 26, pl. XIII and fig. 28, pl. XIV). The inclusions are oriented in zones //(001), giving salite striations to the mineral. Orientation //(100) is more rare. The apparent grainsize of augite is very small, usually less than 1 mm, but in polarized light is seen that seemingly isolated grains belong to the same crystal, the size of which is 1—3 cm. If classification is based on these large augite-crystals, the olivine dolerites should be termed coarse-grained rocks. However, since the real grainsize of this mineral can be disclosed by the microscope only, and the apparent grainsize is as fine as that of plagioclase, the term fine-grained is probably still justified. Iron ores, always interstitial, (fig. 26, pl. XIII) are mostly accessory minerals, but sometimes they constitute 5 per cent of the rock. Other accessories are: spinel, apatite, and perthitic orthoclase. Apatite is idiomorphic (hexagonal prismatic), orthoclase is strictly anhedral, filling up the polyhedrons between the plagioclase laths. In a single occurrence, a large dolerite lense close to the little village of Spjelkavik, an optically anomalous ortho-pyroxene is found as a primary constituent, though in small amounts. This rock is a type transitional to the noritic olivine dolerite, to be described below.

Owing to the general pigmentation of plagioclase (and augite), the olivine dolerites look black, with a violet cast. They are pretty rocks, quarried for monument stones (tombstones). On the weathered surface of the rocks a conspicuous, spheroidal structure is seen (fig. 4, pl. II). The diameter of the spheroids is about 2—3 cm, which is equal to the real grainsize of the ophitic augite crystals. This probably explains the structure.

Some extremely olivine-rich dolerites have been termed troctolitic dolerites by the author. Their estimated, primary composition is:

Plagioclase	40—60 %
Olivine	30—50 »
Augite	1—15 »
Accessories	2 »

These rocks are fine-grained, dark green in color, with a brown cast on the weathered surface, caused by decomposition of olivine, and may easily be confused with dunites. Only two small lenses of this rock type have been found in Sunnmøre. Chemical analyses, norms and modes of specimens from these localities are given in tables 3 and 4 on pp. 79—80 (Nos. IV and VI). Specimens found in the collections of the Mineralogical-Geological Museum of the University of Oslo show that a third locality is in the neighborhood of the city of Kristiansund (north of Sunnmøre). This locality is represented by No. VIII in table 5, p. 81.

Since some of the olivine dolerites are very rich in olivine (about 20 per cent), there is probably a contineous transition between the two types. In the two troctolitic dolerites found in Sunnmøre, alteration is so advanced as to render quantitative calculations of the primary mineral composition very difficult. No doubt augite is of minor importance, constituting only 2—3 per cent of the rocks, or even less. However, in the locality of Kristiansund, augite is rather abundant (15 per cent). The accessories apatite, iron ores and spinel are even more scarce than in the olivine dolerites. Orthoclase and primary orthopyroxene are not observed at all.

The plagioclase of this dolerite type is so decomposed that an accurate determination by optical methods is impossible. The normative composition is An 61—67. Olivine, and to a less extent also augite, are more magnesian than in the olivine dolerites. The textural relations of the minerals of troctolitic dolerites are similar to those of the olivine dolerites, but since augite is less, and olivine more abundant, and the latter, often occurring in clusters, is more idiomorphic in shape (fig. 5, pl. III), the ophitic texture is less prominent.

In a boulder not far from the hypersthene-bearing olivine dolerite at Spjelkavik, the optically abnormal hypersthene is the most important femic mineral (of primary origin). The estimated, primary composition of this noritic olivine dolerite is:

Plagioclase	60—70 %
Olivine	10—15 »
Hypersthene	15—20 »
Augite	5—10 »
Accessories	3 »

This rock has a somewhat different texture from the other olivine-bearing dolerites, since it seems to exhibit large phenocrysts of hypersthene. It is worthy of notice that the texture is pseudoporphyric, only, the outlines of the insets always being determined by the plagioclase laths (fig. 6, pl. III). It is seen that the large hypersthene crystals, like the ophitic augite crystals, enclose hypidiomorphic olivines and plagioclase laths, but of smaller size and quantities; hypersthene therefore stands out more conspiceously as phenocrysts. Otherwise augite and hypersthene have the same textural relations, with augite usually exhibiting larger real grainsize.

The composition of olivine and plagioclase is the same as that of the common olivine dolerites, the former, maybe, a little more magnesian. Hypersthene is optically anomalous(detailed description on p.74). The rock also contains a little interstitial iron ore and orthoclase, and trifling amounts of apatite and spinel (see No. III, table 5, p. 81).

Olivine-free dolerites.

These rocks are probably even more abundant and more widely distributed than the olivine-bearing dolerites. The chief, colored minerals are augite and iron ores. Hypersthene is always present, but is easily overlooked, since it rarely constitutes more than 2—3 per cent of the rocks. The estimated, primary composition is:

Plagioclase	50—60 %
Augite	20—30 »
Iron ores	5—10 »
Other minerals ...	5—10 »

The chemical composition, norm and mode of an ordinary, olivin-free dolerite is represented by No. VII in tables 3 and 4, pp. 79—80. No. II, table 5, p. 81 gives the mode of another.

The minerals of these coarse-grained dolerites as a rule are more altered than those of the fine-grained olivine dolerites. Plagioclase specially is decomposed, and probably it has primarily been an acid labradorite, although it now is slightly below An 50. It is not appreciably zoned, and opaque dust is rarely observed. Augite and hypersthene contains many Schiller inclusions, (striation plane predominantly (100)), but these are of larger size than in the olivine dolerites, and do not make the host minerals look opaque. Hypersthene is optically normal. Orthoclase is of the same perthitic type as in the other rocks, and while it mostly fills up sharp-edged interstices, it sometimes protrudes as tongues into the plagioclase laths. It is very unevenly distributed in the rocks, one thin section contained 7 per cent, while in others it is not observed at all. The average amount is probably 3—5 per cent. The iron ores consist, as in olivine dolerite, partly of magnetite and ilmenite in individual grains, partly of oriented plates of ilmenite in magnetite. Green spinel is also imbedded in the ore, predominantly as individual grains, and to less extent as oriented inclusions. The ores in these rocks do not show idiomorphic crystal faces. Apatite, also, is more abundant. Despite the idiomorphic habit, it is found in the interstitial minerals, especially in orthoclase. Plagioclase laths are sometimes enclosed by hypersthene, but rarely, if ever, by augite. Hypersthene sometimes exhibits a stronger tendency towards idiomorphic outlines than augite, but they are both predominantly interstitial. Most frequently, the two kinds of pyroxene occur in separate grains, very often clustered together, or crystallographically intergrown in two different ways:

1. Large hypersthene crystals have intergrown with still larger augites along the crystallographic c-axes, thus the prismatic cleavages cross the contact without any change of direction (fig. 7, pl. IV). When completely enveloped by augite, this hypersthene does not exhibit any individual crystal faces, but shows irregular, though smooth outlines. Investigations by the Universal stage method disclose that the following relations exist:

$$N_{\alpha\ \text{rhomb}} = N_{\beta\ \text{mon}};\quad N_{\gamma\ \text{rhomb}} \wedge N_{\gamma\ \text{mon}} = 40^\circ \pm;\quad c_{\text{rhomb}} = c_{\text{mon}}$$

$$N_\beta\, N_\gamma\ \text{plane}_{\text{rhomb}} = \text{Optical plane}_{\text{mon}}$$

2. A great number of small, irregularly bounded hypersthene-crystals, extinguishing simultaneously, are enclosed in one large augite-crystal (fig. 8, pl. IV). This is a sort of perthite structure (cf. the picture of patch perthite of felspar, given by Anderson, 1926, pl. III, fig. 16 A.)

In a single occurrence of olivine-free dolerite, on the Grimstad cape of the island of Ellingsøy, (NE of Ålesund), hypersthene is an essential mineral. The primary composition of this rock is probably:

Plagioclase	50 %
Augite	20—25 »
Hypersthene	15—20 »
Iron ores	10—12 »
Accessories	2 »

The chemical composition, norm and mode is given in tables 3 and 4, pp. 79—80 (No. V). It is clear that the increase of hypersthene has occurred mainly at the expense of felspar, and that iron ores are very plentiful. Otherwise this rock shows no important differences from the other olivine-free dolerites.

Dolerite pegmatite.

In the central parts of the dolerites, most frequently in the coarse-grained, olivine-free rocks, irregularly bounded veins or aggregations of very coarse-grained dolerite minerals are found (fig. 9, pl. V). In places, they are more regularly bounded, resembling dikes. These dolerite pegmatites, or pegmatoids, are always so much altered that quantitative measurements of amount and composition of the primary minerals cannot be made. The essential constituents of primary origin are: plagioclase, augite, and iron ores. A few hypersthene crystals and some orthoclase are observed, as is quartz, but it is not possible to ascertain that quartz is a primary mineral. The plagioclase crystals sometimes measure 10 cm, and augite crystals of fist-size are found. A schlieren structure is formed by concentrations of iron ores and pyroxene, mostly along the contacts of the pegmatites.

Metamorphism of dolerites.

After the solidification of the dolerites, the pyrogenic minerals have taken part in large-scaled transformations of different kinds. No completely fresh dolerite has been observed in the area. In the least altered types the primary minerals are seemingly fresh, except for the pigmentation, but reaction rims (coronas, etc.) have been formed between them. The metamorphism of the dolerites has been a continuous process, which can be traced microscopically step by step, and whose final product is an amphibolitic rock without any trace of primary minerals and structures.

The mineral reactions, to a great extent, are very similar in the two main dolerite groups. The olivine-free dolerites, however, are always more altered than the freshest types of olivine dolerite, and it is most convenient to describe the first phases of mineral-reactions of the two groups separately.

Early stages of alteration of olivine-bearing dolerites.

Around olivine, at the plagioclase-contact, a wide, double corona is present, the inner part of which consists of orthopyroxene, the outer one of garnet (fig. 10, pl. V). In some places a bluish green amphibole has formed, either intergrown with the garnet, or in a third corona outside garnet. In addition to the coronas, semi-opaque zones are seen, either on both sides of the garnet-corona (fig. 12, pl. VI), or on one side only. In some of the troctolitic dolerites they are so wide as to replace most of the plagioclase crystals.

Between adjacent iron ores and plagioclase, biotite-coronas may be formed towards the ore, and garnet-coronas towards plagioclase. Sometimes, the biotite-corona is missing, and a wide rim of garnet is the only corona. In a few cases the garnet-corona is absent, giving place to a corona of brownish yellow amphibole.

At this early stage of alteration, there is usually no reaction rim between augite and plagioclase. Sometimes a thin corona of garnet is observed (fig. 2, pl. I), less frequently of amphibole or biotite. Between (the abnormal) hypersthene and plagioclase a double corona is formed; towards the hypersthene, a rim of another, optically normal, orthopyroxene is found (fig. 6, pl. III), which sometimes alternates with clinopyroxene (diopside?), and towards plagioclase, a rim of garnet. The coronas of this orthopyroxene thus are almost the same as those of olivine, but they are much thinner.

Shortly after the rim reactions took place, innumerable, tiny crystals are formed in plagioclase, often converting it to a grey mass in which the original lamination is almost completely obliterated (figs. 10 and 12 pls. V and VI). Simultaneously, the brown dust commences to disappear. The tiny reaction products, too small to be identified, seem to fall into two types: irregularly rounded crystals with low index of refraction and birefringence, and micalike minerals of moderately high index of refraction and high birefringence, mostly arranged in a grating pattern within plagioclase (fig. 11, pl. VI).

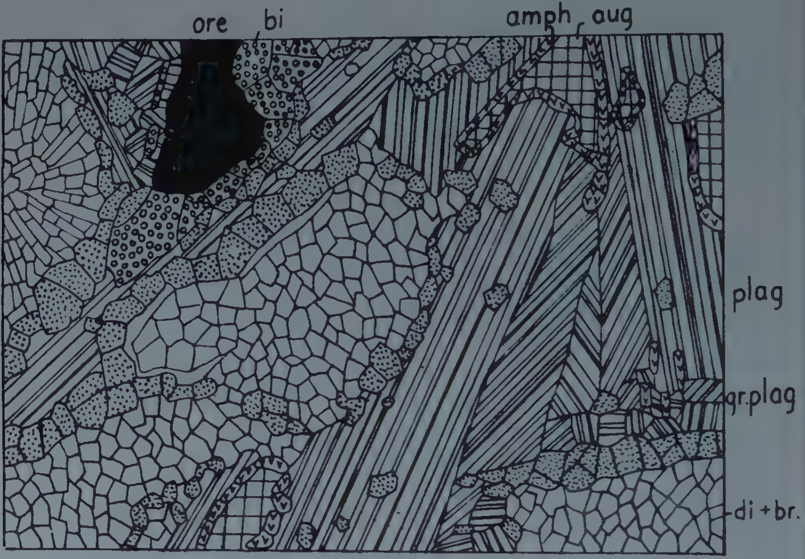


Fig. 3. Pyroxene-pseudomorphs after olivine, surrounded by garnet coronas with idiomorphic front towards plagioclase. At some places, a little rim of plagioclase is left inside the garnet corona. The section is drawn after micro-photo, fig. 13, pl. VII. Magnification 45.

The olivine-core is commonly remarkably fresh, only some small veins of secondary iron ore, and exceptionally of serpentine, are seen. Augite seems to be very stable at this stage, and the inner part of iron ore is not attacked.

The coronas grow steadily at the expence of the primary minerals. In olivine, one or two new orthopyroxene-coronas may appear on the inner side of the first one, finally replacing the whole olivine-grain. However, the olivine-core is, at a certain stage, more frequently replaced by a mass of granular orthopyroxene (fig. 3 above, and fig. 13 pl. VII), or by a mixture of granular iron ore and orthopyroxene (fig. 12, pl. VI). During this process some of the orthopyroxene is replaced by diopside, at first in the coronas, later on also in the central, granular mass. In a few cases a continuous diopside-corona is observed between the garnet-corona and the inner coronas, even before olivine is completely replaced. Later on, amphibole begins to replace both orthopyroxene and diopside in the coronas. In the garnet-corona, idiomorphic crystal faces form, especially on the plagioclase side (fig. 13, pl. VII), but still the rim is continuous. Inside the original

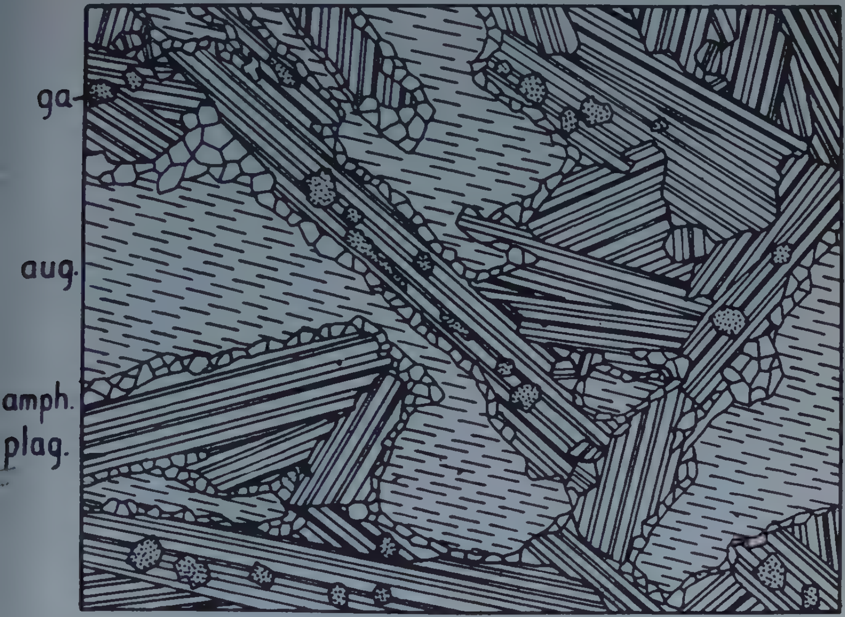


Fig. 4. Amphibolitization of augite edges. Scattered garnets in plagioclase at some distance from augite. Drawing of micro-photo fig. 14, pl. VII. Magnification 45.

plagioclase laths, the reaction-products are increasing in size, but decreasing in number, the brown dust entirely disappears, and small, clear, granular plagioclase crystals, more acid than the original laths, are formed, mainly along the garnet-corona and at the mutual contacts of plagioclase laths. Reaction rims appear between different kinds of colored minerals: orthopyroxene between olivine and augite, garnet between iron ores and augite, and biotite or garnet between olivine and iron ores. When imbedded in plagioclase, augite still does not form any coronas, only a few scattered, idiomorphic garnets are seen along the contact. Instead, augite is uralitized along the edges (cf. fig. 4 above and fig. 14, pl. VII). The inner corona of the primary orthopyroxene is replaced by fibrous diopside, which, especially in the direction of the c-axis, penetrates deeply into the host crystal. Biotite forms a thick and continuous inner corona around iron ores, the outer corona of garnet likewise increases, and plagioclase laths, protruding into iron ores, may be completely converted to garnet laths.

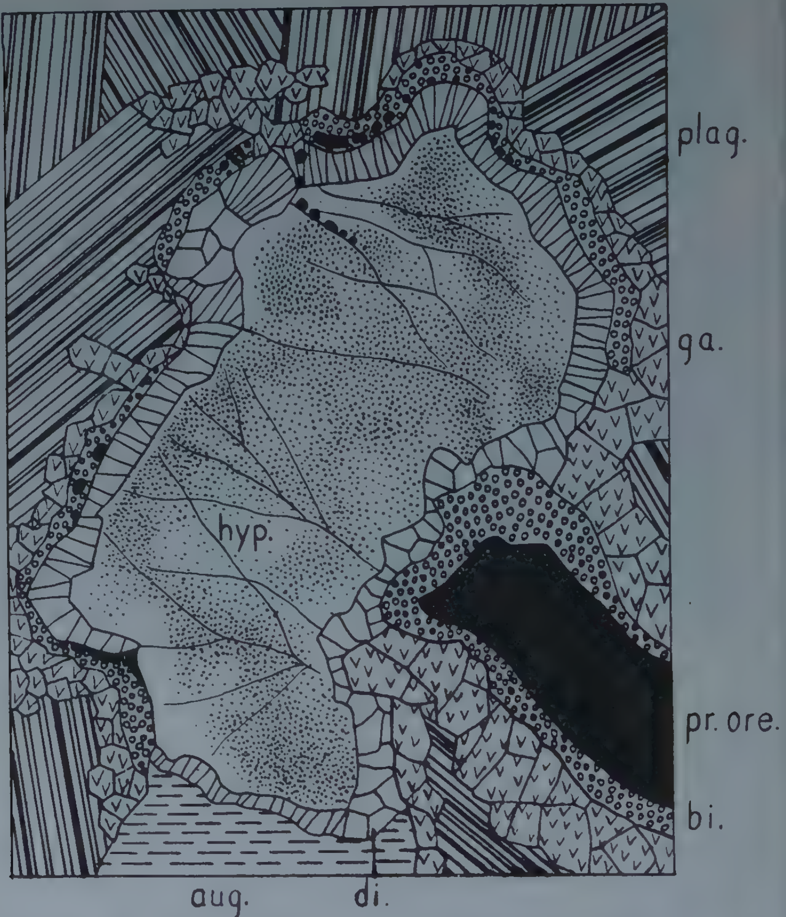


Fig. 5. Coronas and concentric alteration of hypersthene. Besides the usual corona-minerals, some secondary iron ores are present, in part in fractures of the hypersthene, most of them, however, in the biotite-corona. In the biotite-corona, the individual crystal bounderies are not drawn. Drawing of micro-photo, fig. 15, pl. VIII. Magnification 45.

Early stage of alteration of olivine-free dolerites.

In these rocks, coarse coronas are formed between all types of colored minerals and plagioclase. The edges of hypersthene crystals are replaced by a rim of radiating diopside, outside this, though separated from it by a thin rim of mostly granular plagioclase, a

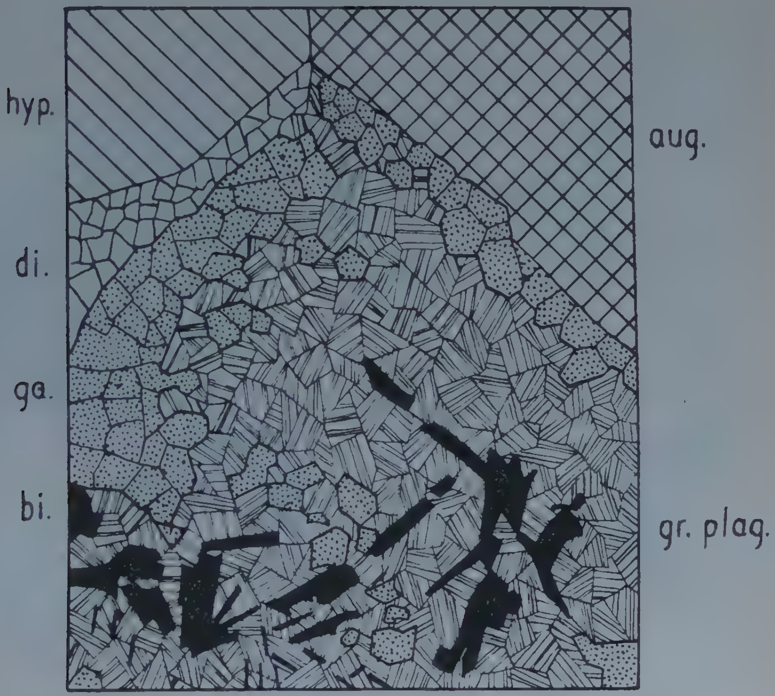


Fig. 6. Coronas between a granulated lath of plagioclase and hypersthene (left), respectively augite (right). — Drawing after micro-photo, fig. 16, pl. VIII. (A little simplified.) Magnification 45.

garnet-corona is situated. Inside the diopside rim there is a zone of varying width, in which the Schiller inclusions of the original hypersthene are lacking. This concentric arrangement of coronas and hypersthene-alteration is reproduced in fig. 5, p. 52, and fig. 15, pl. VIII. Outside augite, a thinner garnet-corona is formed, (fig. 6 above, and fig. 16, pl. VIII). Usually augite is less altered than hypersthene, sometimes it is edged by granular diopside, which only rarely forms a continuous corona. In a few cases amphibole and biotite are found instead of garnet, but more frequently, these minerals replace the granular rim of plagioclase between the coronas. Symplectic intergrowth of garnet and plagioclase, sometimes also of garnet and diopside, is observed in the coronas. Iron ores display the same coronas as they do in the olivine-bearing types, but the garnet-rim is coarser. Biotite may, or may not, form the inner corona.

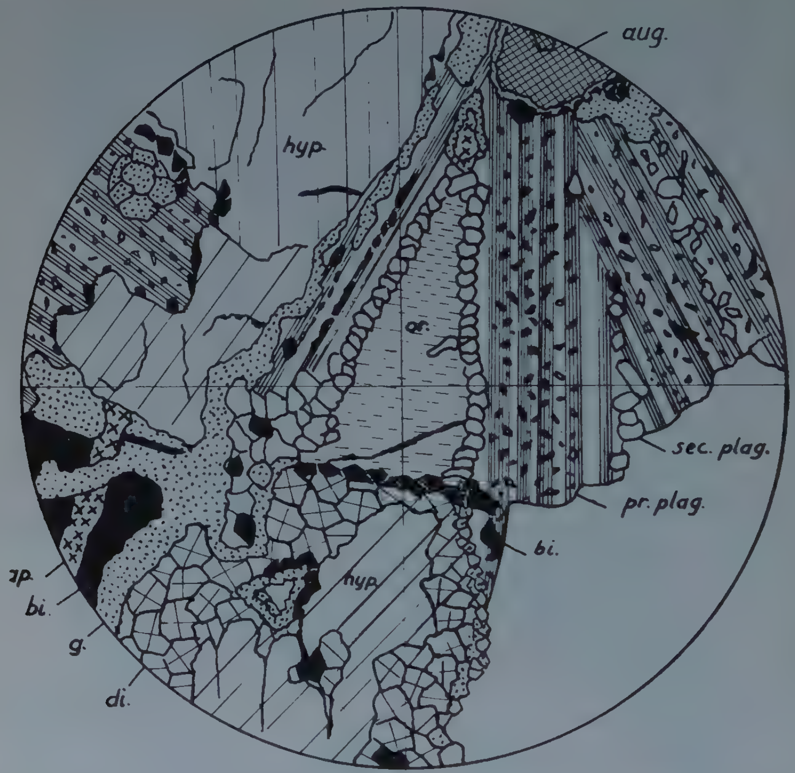


Fig. 7. Section of an olivine-free dolerite. Note the "reaction" minerals of the orthoclase crystal in the central part: towards hypersthene a rim of biotite, towards plagioclase a rim of granulated plagioclase! Also note the garnet-corona of the apatite crystal at the upper corner of the orthoclase crystal. — Drawing of micro-photo, fig. 27, pl. XIV. Diameter about 2 mm.

At a more advanced stage of metamorphism, thin and incomplete coronas form at the contacts of the femic minerals and orthoclase. Garnet-coronas are most common, but biotite coronas are formed more frequently than between the femic minerals and plagioclase (fig. 7) . Often the coronas only form a wedge into the orthoclase, however.

The coronas of dolerite pegmatite are most conspiceous, the garnet-corona may be several mm wide, and amphibole, which in this rock seems to be more common around augite than in the other types of olivine-free dolerites, is visible to the naked eye.

Even in the best preserved types of the olivine-free dolerites, the plagioclase is entirely filled with secondary minerals of the same types as in the plagioclase of olivine dolerite, but somewhat coarser. The grating pattern of the mica-like minerals is sometimes extremely well formed (fig. 11, pl. VI). As the mineral grows larger, it developes the pleochroism of biotite. Whether this means that another mica-mineral (sericite?) changes to biotite during growth, or that the crystals earlier were too tiny to show the pleochroism, is not easy to tell. The other reaction-product, irregularly rounded in shape, is not comparable to any other mineral to be identified at later stages of metamorphism. Only two suggestions can be offered: it may represent the micalike mineral in approximately basal sections, (then the birefringence would be low), or it is some mineral which becomes unstable and is resorbed before it becomes large enough for identification.

Granulation of plagioclase is a common feature in the olivine-free dolerites, and sometimes the original laths are preserved as pseudomorphs only.

From the advanced corona-stage on, the mineral reactions in both main dolerite-groups can be described together.

Middle stage of dolerite alteration.

The mineral reactions now begin to depart from the firm corona-confinement, and the size of the secondary minerals increases greatly. Instead of a continuous garnet-corona, individual garnet crystals grow, most of them still at the original contact, but also along cracks (fig. 11, pl. VI or in the interior of plagioclase crystals (fig. 8, p. 56, and fig. 17, pl. IX). The idiomorphic habit of the garnet crystals at this stage is conspicuous. But pseudomorphs of garnet after plagioclase laths, which protrude into, or are enclosed by pyroxene or iron ore are very characteristic, too, (fig. 7, pl. IV). The granular plagioclase crystals begin to grow together. Sometimes alteration of plagioclase takes place without granulation, but even so, more acid plagioclase of granoblastic appearance, is formed. Augite mostly is uralitized without granulation, sometimes it is converted to a granular mass of diopside and some plagioclase, in more or less symplectic intergrowth, (fig. 18, pl. IX). Orthopyroxene, on the other hand, is usually altered to granulitic diopside before uralitization.

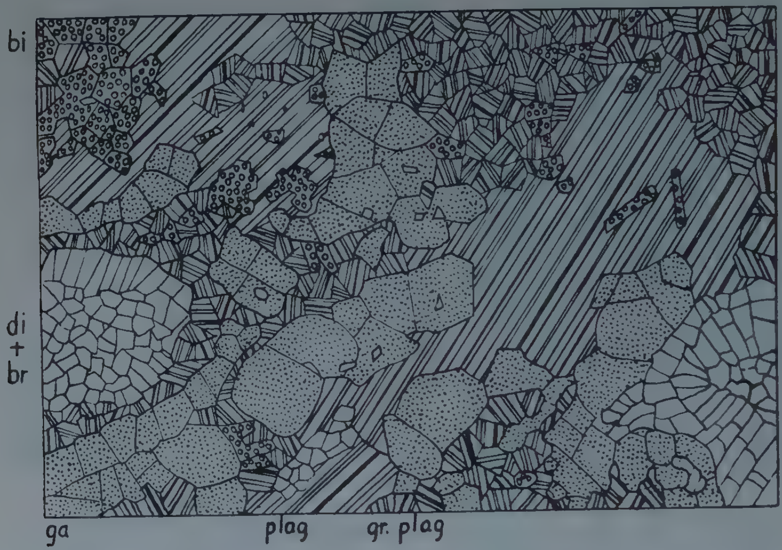


Fig. 8. Advanced alteration of olivine dolerite. — Drawing after microphoto, fig. 17, pl. IX. Magnification 45.

In some places a symplectic intergrowth of diopside and magnetite is formed after hypersthene. Diopside, and later on also amphibole, completely replaces orthopyroxene in the olivine pseudomorphs. (The initial step of this process is amphibolitization of the corona, while the granular pyroxene in the core persists).

The author somewhat hesitates to apply the term "corona" on the zones of biotite and amphibole. They certainly are reaction rims, but the two minerals are usually not truly synantectic.

During growth, amphibole loses the original light bluish green, or brownish yellow pleochroism, and the greens become more vivid. The amount, as well as the grainsize of biotite, greatly increases, at the expense of primary minerals and anhydrous corona-minerals. Biotite-pseudomorphs after iron ores are sometimes observed (fig. 19, pl. X). This replacement, which begins with an ordinary biotite-corona, can be followed step by step (even within a single thin section.) Otherwise, these pseudomorphs could not be distinguished from interstitial biotite of primary origin.

Orthoclase completely disappears during the reactions. The rocks still preserve some of the ophitic or coronite textures, at least as

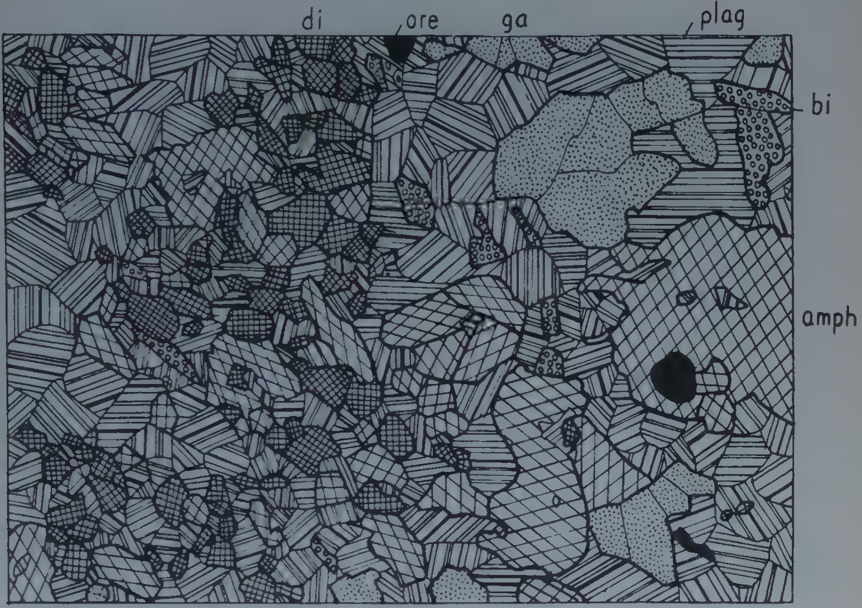


Fig. 9. Granoblastic texture of completely altered dolerite. Drawing of micro-photo, fig. 20, pl. X. Magnification 45.

palimpsests, but they rapidly approach granoblastic patterns. Owing to the abundance of garnet, the rocks have a red cast, but often local concentration of amphibole and biotite develops dark green patches. Garnet still exists in these patches, but it certainly seems to be resorbed.

End stage of metamorphism.

The development of metamorphism is somewhat different in the contact zones and in the interior parts of the rocks. At the gneiss contact, the dolerite is converted to an ordinary schistose biotite amphibolite, containing, besides the two femic components, only oligoclase (An 25—30) as an essential constituent. No anhydrous, femic minerals have survived, and no trace of primary or coronite textures is left. This contact zone usually is only a few meters wide.

At the contact of some transgressive, granite pegmatites the same mineral assemblage is found in the dolerites, however with unoriented, granoblastic texture. Biotite is even more abundant there.

In the interior parts of the completely altered dolerites, garnet and diopside still are essential components, the former may be so plentiful as to make the rock look like an eclogite. Diopside mostly occurs in small grains, intergrown with plagioclase (oligoclase). Antiperthitic plagioclase is found some places. Amphibole and biotite are major constituents in the interior parts, too. The two minerals seem to be able to digest any other mineral during the end stages of metamorphism. Garnet is most resistent, but is finally resorbed. Neither orthoclase nor microcline is observed at this stage, quartz is present in some rocks. Most of the iron ore is resorbed, but locally it is altered to rutile. The texture of the rock is granoblastic (fig. 9, p. 57, and fig. 20, pl. X) usually with a feeble orientation of biotite and amphibole. Traces of doleritic textures or coronas are not easily seen in the thin sections. Occasionally garnet has kept some of the corona-pattern, and may even be found in pseudomorphs after plagioclase laths. On the weathered surface of the rock a faint reminiscence of the dolerite texture sometimes can be traced.

Dolerite dikes.

In a large olivine-free dolerite lense at Haramsgrend on the island of Haram, the dolerite is cut by a great number of dikes and veins of a finegrained, grey rock (fig. 21, pl. XI) mostly a few cm to 1 m thick. They also seem to cut through the secondary schistosity of the dolerite, but in some places it is observed that the foliation of the dikes, caused by oriented biotite, follows the schistosity of the dolerite. A thin-section of a specimen from the point of contact shows a complete conformity (of secondary origin) between the dike and the dolerite, though the contact itself is very sharp.

The chemical composition, norm and mode of the dike are given by No. VIII in the tables 3 and 4, pp. 79—80. Other specimens contain more biotite and amphibole. The grainsize of plagioclase is approximately 0.1 mm, for the femic minerals even less. The grainsize also decreases towards the dike-selvage. The texture is granoblastic, the femic minerals forming a kind of mesh-structure in the plagioclase-matrix. Some of the adjacent plagioclase-grains show simultaneous extinction, perhaps indicating a larger grainsize formerly. Biotite often exhibits parallel orientation, and chains of garnet-crystals follow the same direction.

Owing to the small size of the crystals, exact determination of the minerals is exceedingly difficult. The plagioclase is an oligoclase, and the pyroxene is monoclinic, probably a diopside. The amphibole occurring in the rock has a brown-greenish pleochroism.

At the dike contact, the secondary minerals of the dolerite are the same as the dike-minerals.

Dikes of this type have not been observed outside the dolerite body.

Granitic dikes and pegmatite in dolerites.

Leucogranodioritic dikes.

One of the dolerite-bodies at Vaksvik is cut by a fine to medium grained, white dike. The contact is sharp and smooth. The only essential mineral besides oligoclase (An 15) which dominates, is quartz. The accessory minerals are: biotite, garnet, chlorite (partly replacing garnet) and allanite. Together the accessory minerals do not make up more than a few per cent of the rock, and thus it must be classed as a leucogranodiorite, or a trondhjemite. The texture is ordinary granitic (granular).

Granite pegmatite.

A number of the dolerites are intersected by granite pegmatites of various size. The largest observed is a 5—6 m wide dike, but the majority are much smaller. The minerals are: quartz, microcline, sodic plagioclase, biotite and muscovite. Garnet is rare. A zonal arrangement of the minerals is often observed, quartz and microcline occupying a central position. The contact between dolerite and pegmatite mostly is sharp, but the dolerite is converted to a biotite amphibolite in the border zone. The width of this alteration-zone is approximately proportional to the size of the pegmatite. Almost invariably shearing phenomena are observed in the dolerite in connection with the pegmatites.

In the hypersthene dolerite at Ellingsøy (pp. 47—48) some really conspicuous pegmatites occur. The locality is not far from the dolerite border, thus the grain-size of the dolerite is comparatively fine. The dolerite is somewhat sheared, and as usual at pegmatite contacts it is altered to a biotite amphibolite. At different places in the shearzone, only a few large crystals of felspar and quartz have grown (fig. 22, pl. XI). At other places, however, they are more abundant, and finally a pegmatite zone is formed, where only isolated fragments of the dolerite can be seen, giving the rock a breccia-like appearance (fig. 23, pl. XII). The next picture (fig. 24, pl. XII), is taken from a roadcut nearby, perhaps in the same shearzone. Here a pegmatite "dike" is developed. with only a few, scattered remnants of the dolerite left, mostly converted to hornblendite. The individual felspar crystals exceeds the size of a man's head. The felspar is almost pure albite (An 5). Potassium felspar is not found and the amount of quartz is subordinate. Quartz and albite both are unusually pure and clear. In another pegmatite in the same dolerite body, porphyroblasts of black amphibole are very abundant, and evenly distributed throughout the dike. In several places it is observed that the amphibole porphyroblasts grow directly from dolerite remnants in the pegmatite.

Pegmatite is abundant in the gneiss which surrounds the described dolerite lense. In these pegmatites, potassium-felspar is a main component. In one place such a pegmatite intersects the dolerite body too, but then the red felspar disappears, and only a white pegmatite with an amphibole-biotite contact zone continues into the dolerite.

In a dolerite body on the island of Hessen, just southwest of Ålesund, another interesting pegmatite occurrence is found. At this place, a number of olivine-free dolerite-lenses are found. The dolerite-body under consideration occurs close to the fortification of Tuenes, and is cut by a shelterpit, which has uncovered an excellent exposure. A section of the locality is given in fig. 10. At a distance of about 10 m from the pegmatite, the rock is a normal, somewhat altered, dolerite of medium grainsize. Reaction rims of garnet and biotite are clearly visible, but both minerals replace the primary minerals outside the grain boundaries too. Plagioclase is altered, but the lathshape is mostly preserved, as a palimpsest. The composition of this plagioclase is An 30—35. Augite is the main mafic component, it is partly altered to biotite and amphibole. Orthoclase (microperthite) is abundant, and quartz is observed. Towards the pegmatite, the dolerite becomes more and more schistose, the primary minerals and structures completely disappear, and a schistose amphibolite, rich in mafic minerals, develops. Then strips of felspar appear, widen out, and finally, close to the pegmatite, a porphyroblastic gneiss, still rich in mafic minerals, is found. The porphyroblasts consist of coarse-grained plagioclase and quartz. The anorthite-content of plagioclase is gradually reduced, in

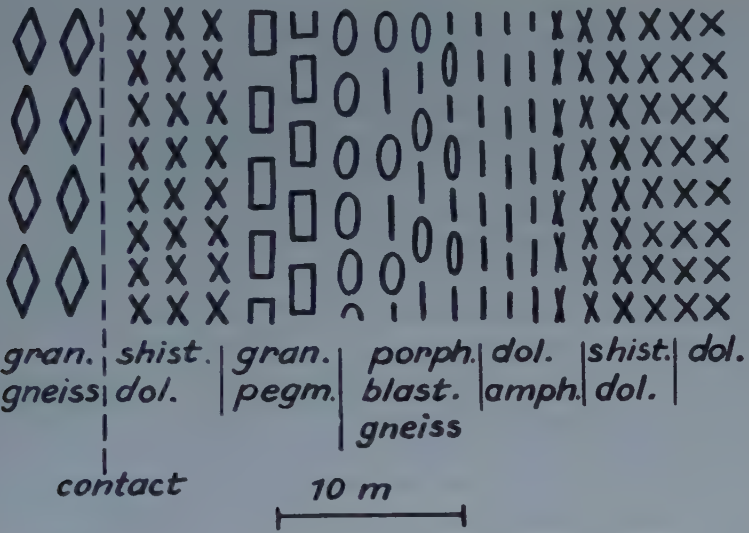


Fig. 10. Section of part of a dolerite at Tuenes, Hessen.

the amphibolite to 25 per cent, in the porphyroblastic gneiss a few per cent lower, still. The amount of quartz increases. The other main minerals are amphibole and biotite, both with intense colors in transparent light, the amphibole dark green, the biotite dark brown-green. Apatite is accessory, but is more abundant and larger than in the dolerites. Garnet is observed in the porphyroblastic gneiss also, but it looks resorbed.

This oligoclase-porphyroblastic gneiss is succeeded outwards by a white pegmatite, a couple of meters wide, paralleling the foliation of the dolerite-amphibolite. Some small, transgressive veins of granite also penetrate the porphyroblastic gneiss. On the outer side of this pegmatite, close to the gneiss border, a very schistose and altered dolerite is found, but no porphyroblasts.

Dolerites of uncertain origin.

Two specimens of dolerite in the collections of the Mineralogical-Geeological Museum at the University of Oslo, are recorded as found within the investigated area. In spite of a timeconsuming search in the field, and otherwise, it has not been possible to find the source of these rocks. One of the specimens (No. IX in table 5, p. 81) is sent to the Museum from a mining company in Ålesund, which has been quarrying some olivine dolerites near Ålesund. The other rock (No. X in table 5) is labelled: "Boulder, Voldersund pr. Ålesund." This name must be fictional, however, as nobody has been able to locate it.

The two rocks seem to be related. Their textures, mineral composition, and alteration show great similarities, though some differance exists.

No. IX has a porphyric variety of ophitic texture. The primary minerals are: plagioclase, An 45, olivine Fa 25, augite ferrugineous, $\gamma = 1.722$, pigeonite, and iron ores. The refractive indices of pigeonite seem to lie in the same range as augite. The optical plane is $\perp(010)$, and $2\,V\gamma = 18° \pm 2°$. The pigeonite crystals are slightly zoned. Zonal phenocryst of plagioclase laths occur, and hypidiomorphic olivine crystals also are seen as insets. Even augite and pigeonite exhibit porphyric grains, but their outlines are always determined by the plagioclase laths, like the pseudo-porphyric hypersthene in the noritic olivine dolerite.

Since one of the abovementioned porphyric dolerites contained pigeonite, the author tested several plagioclase crystals in the same thinsection for possible high-temperature optics. When using the maximum extinction method (Rittman) the two sets of albite twins generally showed different extinction curves. In a fresh crystal exhibiting Carlsbad twinning, the extinction method gave respectively 50 and 56 per cent anorthite. When Koehlers sensitive twin optics method was employed, 53 and 40 per cent An were obtained by low-temperature curves, but 43 per cent in both lamellae by high-temperature curves. The plagioclase of this rock therefore probably crystallized in the high-temperature phase. It contains only minor amounts of brown dust, and also augite and pigeonite are clear and mostly free of Schiller inclusions. Corona structures are not typical, except around ores, where a composite corona of amphibole and biotite is found. The large crystals of plagioclase and pyroxene mostly are fresh. In some places pyroxene grains in the small interstices of plagioclase laths, are altered to a mixture of bluish-green amphibole, biotite and probably also some chlorite. From these interstices alteration has continued into the adjacent plagioclase laths. Thus the alteration has a patchy distribution in the rock. Olivine sometimes has a rim of orthopyroxene (?) but is mostly replaced by serpentine and ore, the latter mineral mostly concentrated in veins and along the border. Where fresh, the olivine has a weak grey-brown color, only faintly pleochroitic in transparent light, and the composition is Fa 20—30, (deduced from the optical axial angle). No. X has an even more pronounced porphyric texture. Large, zonal insets of plagioclase are common. Scattered insets of idiomorphic olivine-crystals are also observed (fig. 25, pl. XIII). The groundmass consists of fine-grained, lathshaped plagioclase with interstitial augite, uniformly distributed throughout the rock. The texture is somewhat between doleritic and subdoleritic. Measurements on the Universal stage disclose that the plagioclase fits neither low- nor high temperature curves, thus no accurate composition can be given, but it is a labradorite. It is only faintly clouded, as in No. IX. The augite, less ironrich ($\gamma =$ 1.707), is not visibly zonal, but the range of the optical axial angles is $2\,V\gamma = 35°—42°$. Owing to scarcity of favorably oriented grains, only 2 measurements of the optical axial angle of the olivine insets have been made. According to them, olivine should contain only some 10 per cent of the fayalite-component.

In this rock almost no trace of coronas has been found. Sometimes augites in the plagioclase-contact have a narrow rim, probably of biotite. Biotite, also, ist he only diagnostable, secondary mineral in pyroxene and plagioclase. The olivine-insets are altered to magnetite and serpentine along the border and in some veins, but as a whole, olivine is fresher in this rock than in the one described above. Ore is more abundant and less altered. Only a narrow rim of biotite may be seen some places.

Additional notes on the mineralogy of the dolerites.

On the methods of mineral identification of extrusive or hypabyssal rocks.

Many of the common minerals occurring in igneous rocks belong to isomorphic series of two or more components, e. g. the plagioclases, olivines and pyroxenes. It has been an object in mineralogical research to establish the relation between the chemical composition and the physical properties, especially the optical ones, of the different mineral series. Considerable progress towards this aim has been achieved during the last decades.

In these investigations it has more or less been taken for granted that the optical properties of the minerals presented a one-valued function of the chemical composition. In the early thirties, however, Barth was able to show that the optical properties of plagioclase crystals had changed after annealing and quenching (Barth 1931).

Since then, the subject has been treated by several authors, especially Koehler. It has been shown that the optical properties of plagioclase of extrusive rocks differ from those of the plutonic and metamorphic rocks due to high temperature of crystallization and rapid chilling of magma.

Koehler (1940) thought that the high- and low temperature plagioclases belonged to two distinctly different series, and issued diagrams for a part of the high-temperature phase. A summary of the work of Koehler and coworkers has been published (Koehler 1949).

Barth and Oftedahl (1946) recorded high-temperature plagioclases in the Oslo-plutonites. The Koehler curves only partly fitted these plagioclases, accordingly Barth and Oftedahl contended that the high- and low-temperature plagioclases did not belong to two distinct series. Of 11 felspars investigated by them, only two fell exactly on the Koehler diagrams for high-temperature plagioclase, the other 9 were systematically displaced between the high- and low-temperature curves. Barth and Oftedahl (op. cit., p. 103) say: "Thus each crystal possesses its individual optical orientation, and, consequently, its individual history of cooling. The temperature of crystallization is not the only governing factor, also the rate of cooling must be considered."

Tomkeieff (1939) has investigated olivines belonging to effusive rocks, and found that they were much more zoned and showed larger compositional variation than olivines occurring in peridotite and dunite. His conclusions were mostly based on the variation of the optical axial angles of the olivines.

Seifert (1941), and independent of him, Chudoba and Frechen (1943) also found great variations in the optical axial angles of olivines from basalts, furthermore they demonstrated that these variations were not accompanied by great variations of the densities of the minerals. Compared to the densities, $2\,V\alpha$ exhibited a systematic decrease of maximum 10—12 degrees, the mean being 3—4 degrees. Chuboda and Frechen thought that the regular variation of the optical axial angle of the olivines and the peculiarities of the high-temperature plagioclase might have a common cause. In order to prove this, they heated and quenched natural olivine crystals. By this operation the optical axial angle over α decreased 3—4 degrees.

The present author found high-temperature plagioclase and pigeonite in a dolerite described on p. 62. There was also found great variation in the optical axial angles of olivines, which could not be referred to zoning. Details are given on pp. 72—73.

It is concluded that the standard diagrams expressing the relations between the optical properties and the chemical composition in the isomorphic series of plagioclases and olivines, cannot uncritically be used for minerals in hypabyssal or effusive rocks. Especially if the rocks contain sanidine, pigeonite, or pyroxenes indicating exsolution of a high-temperature phase, plagioclase and olivine should be tested for possible high-temperature optics.

The question which now arises is: to what extent does the matter of high-temperature crystallization affect the usual optical identification-methods for the common rockforming minerals? Some considerations concerning plagioclase, olivine and pyroxene shall be given here.

Plagioclase.

Koehler demonstrated by his sensitive, twin optics method that the high-temperature crystallization effect on the optical properties of plagioclase consisted of a change of form and position of the indicatrix. Because of the relation between the optical axial angle and the principal refractive indices, this also means some change of the indices.

Owing to the change of orientation of the indicatrix, the standard Universal stage methods (the migration curve method as well as the extinction angle method) give incorrect results, mostly too high in anorthite-content. As far as the present writer knows, no work has yet been published showing quantitatively the effect on the principal refractive indices. But even if this effect is negligible, the usual method of determining indices on the cleavage planes, is rather gravely affected, since orientation of indicatrix is involved.[1] The sensitive, twin optics method of Koehler can only be used when the twin lamellae are broad enough to avoid interference during tilting of the stage. Furthermore, the adequacy of his diagrams may be questioned.

---

[1] After this had been written, a paper of Bowen, N. H. and Tuttle, O. F. appeared (Journ. Geology 1950 pp. 572—583). It shows (p. 577) that all refractive indices, the orientation of indicatrix, and the optical axial angle have been affected. Especially the optical axial angle, and the extinction angle in the zone ⊥ 010 were greatly changed.

The present state of the optical methods of determining the plagioclases in question thus seems rather inadequate. There is an urgent need for the determination of the principal refractive indices of plagioclases, showing high-temperature optics, by Universal stage methods like those proposed by R. C. Emmons (1943), combined, of course, with quantitative chemical investigation.

Olivine.

The forsterite-fayalite relation of olivine is usually determined by refractive indices, optical axial angle, or density. Tomkeieff (1939 p. 234) states that: "Compared with the other methods, the determination of the optical axial angles presents the simplest and surest means of arriving at the chemical compositions of the olivines."

However, as shown by Chudoba and Frechen, rapid chilling of the olivines particularly affects the optical axial angle. According to these authors, it is necessary to make a number of 2V-determinations to get even an approximate determination of the chemical composition. In their opinion, the highest value of $2V\alpha$ should give the best approximation (1943 p. 101). Before the present author was aware of the works on olivine by the geologists mentioned above, he had tried to establish the relationship between the optical axial angles and the principal refractive indices of olivines described in this paper. Since the equipment necessary for the determination of the corresponding optical axial angles and refractive indices was not available, only the maximum γ and the minimum α could be determined in the sample, which of course was taken from the same specimen as the thin section. The determination of the refractive indices was made by the usual immersion methods using sodium light. The olivines were not appreciably zoned. Only the conclusions are given here, details are presented under the description of the olivines. Attention is especially drawn to the diagram fig. 11, p. 73.

1. The olivines of the dolerites of Sunnmøre show a regular variation of the optical axial angles which can be referred neither to zoning nor strain.

2. The variation consists of an increase in $2V\alpha$ a maximum of 10—12 degrees, the average being about 5 degrees, compared to the value inferred from the principal, refractive indices.

The results of this investigation thus confirm the statements of Chudoba and Frechen as to the anomalous character of the optical axial angles. However, in this case there is an increase of $2V\alpha$ instead of a decrease, as found by the German authors. When making this statement, it is assumed that the refractive index γ is not appreciably changed by the high-temperature crystallization. The validity of this assumption shall be evaluated below.

In the Breven dolerite dike, Krokström (1932, a, pp. 256—58) found great variations of the optical axial angles of olivines whose densities seemed to be constant. He also determined some principal refractive indices. According to Krokström the $2V\alpha$ values corresponing to respectively the density and the refractive index should be identical and amount to 81°. He measured the optical axial angles of 8 crystals and found that $2V\alpha$ ranged regularly between 75° and 88°. Thus the data given by him seem to bridge the gap between the results from Dreiser Weihe and Sunnmøre. They also seem to indicate that the refractive indices are not greatly affected by high-temperature crystallization. It should be mentioned, however, that Krokström himself did not consider high-temperature crystallization. He thought that his extreme values, at least, were due to some methodical error.

In his work on the zoned olivines, Tomkeieff (1939) in several cases has found pure forsterite in the core of olivine crystals, the composition deduced from the optical axial angle. If Chudoba and Frechen are correct in stating that the highest $2V\alpha$-value gives the best approximation of the composition, Tomkeieff, making one or two determinations per specimen must have, by chance, got the highest value in each case. According to Chudoba and Frechen (1943, p. 99) this does not seem reasonable: "Bei der geringen Anzahl der gemessenen Werte für ein Gestein ist sicherlich nicht überall der maximale Betrag der Abweichung der Achsenwinkel bestimmt worden". Furthermore, there are good reasons to doubt that the olivine cores are completely devoid of iron. It is more reasonable to think that the chemical composition deduced from the optical axial angles in these cases is too high in magnesium.

The investigations of the present author can only give some hints toward answering the question of whether or not the principal refractive indices of olivine have been affected by the high-temperature crystallization. It will be seen (fig. 11, p. 73) that the birefringence γ-α of every specimen investigated is almost normal. Thus, it does not seem that the highest and lowest index is appreciably influenced. The question can be adequately answered only by obtaining all the different optical properties in one particular grain by Universal stage methods. As long as this is not done, direct comparison of the olivine-investigations carried out by the two German geologists and the present author, may not be practical. To some degree, however, they seem to contradict each other.

According to the data presented above and the papers quoted, it should be right to conclude:

1. Tomkeieff's statement concerning the use of the optical axial angle in identification was too favorable.
2. The optical axial angles of olivines in rapidly chilled igneous rocks show a rather great variation, which is not attended by corresponding variation of the chemical composition, but more data are necessary before final conclusions can be drawn as to the nature of these variations.
3. Density-determination of (high-temperature) olivine should give the best estimate of the chemical composition. Unfortunately, it can be accurate only when the grains are large and free of inclusions or reaction products. Therefore this method is restricted in use.

Augite.

It is well known that the optical axial angles in augites of basalts and dolerites often show a considerable range, even within the same thin-section. No doubt the reason in many cases is zoning, or, as is commonly assumpted, a different content of minor elements. The present author thinks it unreasonable to exclude the possibility of temperature effects during crystallization. Attention should be given to the phenomenon described by Walker and Poldervart (1949, p. 631): "The presence of some subsidiary line (on the clinopyroxene crystallization trend curve) is indicated by the fact that pyroxenes having a γ-index of, say, 1,730, were found to have an optical axial angle of either 31° or 44°." The authors think this means that the low-angled type contains less Ca, but the reason may also be that the two types have crystallized under different thermo-dynamical conditions. The effect of temperature on the optics of felspar and olivine should make us critical, and caution should be exercised in deducing the chemical composition of augites from optical angle determinations in rapidly chilled igneous rocks, like basalt and dolerite.

Methods used in mineral identification in this paper.

Most of the determination of minerals has been made in standard index oils, which were previously checked by a refractometer. In order to get a satisfactory concentration of the different minerals in the finegrained rocks, the specimens were crushed and sieved, and the felspars and other light components were separated from the mafic minerals by means of acetylene-tetrabromide. Separation by means of an electro-magnetic separator was not satisfactory, for reasons to be given below. The calibration of the index oils did not allow a limit of error less than 0,002—0,003.

In a considerable number of specimens determinations of the optical axial angle was done on a 4-circle Universal stage (Leitz) whose lenses and segments were tested for possible double refraction. In many cases, however, it was impossible to get sharp extinctions because the minerals, especially augite, but also hypersthene and plagioclase, were clouded by innumerable inclusions of submicroscopical iron ore. Often these inclusions also interferred with the movement of the Becke line during the index-determinations, and probably induced magnetic properties to the otherwise non-magnetic minerals, making electro-magnetic separation fail.

Many of the primary minerals are partly altered, and the secondary crystals are often so tiny that optical determinations are exceedingly difficult to carry out. The author has spent much time trying to get as correct determinations as possible, but owing to the described difficulties, he cannot claim too high accuracy for the results. In most cases indices in the cleavage planes of plagioclase, and the extinction angle in the zone ⊥(010) have been determined. Usually the twin lamellae are not broad enough to allow determination of the orientation of indicatrix, but this has been made when possible. In most cases, the Koehler sensitive twin optic method has been used, sometimes also the standard migration curve methods.

The calculation of the anorthite-albite relationship is often made by averaging the results obtained by different methods.

Measurements of the optical axial angle of several grains of olivine in a section, and of the γ-index, and sometimes also of the α-index of the minerals, were made. The chemical composition has been deduced from the γ-index, according to Wager and Deer's diagram (1939). As mentioned above this may give somewhat incorrect results, but the author considers it safer than to rely upon the optical axial angle.

Density-determinations have not been carried out, as the olivines always are coated by coronaminerals, and some are replaced along cracks by iron ore.

The γ-index of orthorhombic pyroxene has been determined, and the composition estimated according to Poldervaart's diagram (1947, b, p. 167). The optical axial angle has been measured as a check.

Hess' method of determining the β-index of augites (1949, p. 627) has been used when favorably oriented grains have been present. Only a few grains in the samples were lying on the parting planes parallel to (100), however, and often a search for the γ-index has been necessary. The present author agrees with Hess (op. cit., p. 628) that the method of determining the index in the cleavage plane (110) is not safe. The chemical composition of the augites has been estimated from the intersections of the refractive index curves with the trend of crystallization curve of augites, worked out by Wager, Deer and Hess (Hess 1949, p. 634). This method is not altogether satisfactory, but the author considers it to be the best one at present, cf. Poldervaart (1947, a, p. 162).

Primary minerals.

Plagioclase. The primary plagioclase of the Sunnmøre dolerites is always lathshaped parallel to (010). Albite twinning is found in almost every grain, and Pericline and Carlsbad twins are common. The twin lamellae mostly are very thin, (albite twins frequently less than 10 μ). The characteristic clouding of plagioclase in the olivine-bearing types, produced by a brown dust (fig. 26, pl. XIII), usually shows no regular distribution. However, in a single case (fig. 6, pl. III) the plagioclase laths enclosed in, or projecting into, pseudoporphyric orthopyroxene are more clouded than the others.(As stated later, the author does not consider the clouding to be a truly primary feature.)

Since the plagioclase of a dolerite of uncertain origin, supposed to be in Sunnmøre, contained high-temperature plagioclase, the author tried to determine whether the plagioclase of the dolerites from known localities exhibits low- or high-temperature optics. Owing to the frequent clouding of the minerals, and the thin twin lamellae, it was difficult to get exact measurements. When using the maximum extinction method, adjacent lamellae often gave very different values. When using the Koehler sensitive twin optics method, neither low- nor high-temperature curves gave satisfactory results. But according to these measurements, either the optical properties of these plagioclases are more or less abnormal, or the chemical composition of adjacent lamellae is different (not to be confused with zoning). The plagioclase of these dolerites is never quite fresh, some corona-reaction has always taken place, and adjacent lamellae of plagioclase may have taken part in the chemical transformations in differing degrees. But even if the original plagioclase crystallized in a high-temperature phase, the metamorphism, which has affected every one of the primary crystals, probably will transform the plagioclase into the more stable low-temperature phase. The rate of this reaction, however, is not known at present. For these reasons, it is difficult to reach a decisive conclusion as to the primary crystallization phase of the plagioclase, and it is not possible to state the chemical composition of the plagioclase accurately. The composition of the cores of the zonal plagioclase in the olivine dolerites, may not be far from An 60. The average composition of plagioclase in this rock is An 50—60. In the olivine-free dolerites, the composition probably has been close to An 50, while in their present state, the range is An 45—55. The serial variation of the plagioclase in this dolerite suite does not seem to be very great. It should be noted, that the normative composition of plagioclase is almost constant (approximately An 60). The potash-content of the plagioclase has not been considered, as it can be determined by chemical analysis only. The formation of antiperthites and mica minerals in plagioclase indicates a fairly high potash-content in the primary plagioclase.

Table 1.

Optical properties of olivines of the Sunnmøre dolerites.

No.		$2V\alpha$	γ	α
I	SM 106	80°. 84°, 86°, 86°, 89°, 92°	1.732	1.689
II	Gb. III, 29	78°, 80°, 84°, 84°, 84°, 85°, 85°, 88°	1.732	1.688
III	M 431	84°, 84°, 87°, 89°	1.740	1.698
IV	M 513	83°, 86°	1.742	1.698
V	SM 45	76°, 79°, 79°, 83°	n. d.	n. d.
VI	SM 2	74°, 77.5°, 78.5°	1.762	1.726

I, II, and IV are troctolitic dolerites, V and VI are common hypersthene-free olivine dolerites, III has accessorial amount of hypersthene.

n. d. = not determined.

Orthoclase. Unlike plagioclase, orthoclase is quite clear, without any opaque inclusions. It often has a peculiar, wavy extinction, and high magnification discloses innumerable perthite spindles (fig. 27, pl. XIV) in some areas of the crystals. The size of the spindles decreases successively towards the edge of these areas, and most probably the peculiar extinction is caused by invisible perthite spindles. Thus orthoclase is micro- to cryptoperthitic.

The optical axial angle of the orthoclase: $2V\alpha = 71°$.

Olivine. Owing to the abnormal behavior of the optical axial angle of the olivines in these dolerites, they were rather extensively investigated. Apart from the reaction rims and some veins with magnetite and serpentine, the olivines are fresh and clear. Zonal growth has not been observed.

The optical axial angles have been determined in a number of specimens, and the principal refractive indices γ and α in some selected specimens. The results are given in table 1 above.

The refractive indices and the corresponding 2V-values of four of these olivines have been plotted and compared with the olivine diagram of Wager and Deer (fig. 11).

From table 1 is seen that specimen II, which has the same indices as I, but is not plotted on the diagram, gives an almost identical range of the optical axial angle. The optical axial angles were measured in other specimens, also, and in every case considerable variation was found.

For more discussion of these phenomena, see pp. 66—68.

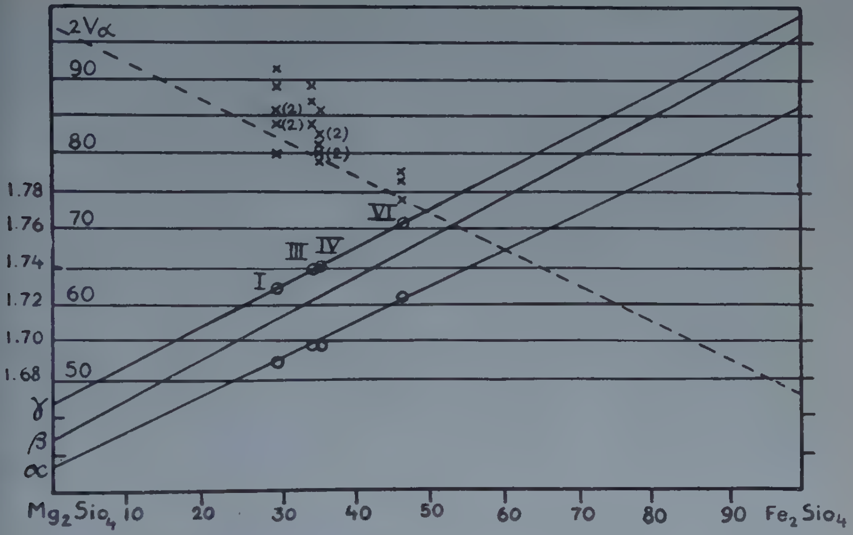


Fig. 11. The optical axial angles and refractive indices of olivines from the Sunnmøre dolerites. (Cf. table 1, p. 72.)

The diagram demonstrates a large range of the optical angles, (in one case even more than 10°) although the birefringence is only slightly greater than that of a homogeneous olivine (the deviation less than the limit of error of index-determination). Owing to the wide optical axial angles of the mineral, steep inclination of the Universal stage during the measurements often was necessary, and an exactness within less than 3° cannot be claimed. Since some of the crystals showed a little undulence, perhaps due to strain, the optical axial angles were determined at different places within them, but the variation within a single crystal never was greater than 2—3°. Thus it does not seem probable that the large range of the optical axial angle is caused by strain. The observed regularity would not be expected if the variations were due to erroneous measurements or strained crystals.

According to the refractive indices, the serial variation of the olivine in the dolerites of Sunnmøre should be from 30—45 Fa, that is in the hyalosiderite group. (The nomenclature of Wager and Deer (1939) is followed.) But if the composition is deduced from the highest $2V_\alpha$-value, the range would be from 12 to 39 per cent fayalite, that is in the crysolite group, mostly. The normative range is from 28 to 39 per cent fayalite, almost the same as deduced from the refractive indices. It is thought that the chemical composition of olivines as deduced from the refractive indices, are more valid than those inferred from the maximum $2V\alpha$ angles. It follows, then, that the olivines of the troctolitic dolerites probably belong near the chrysolite hyalosiderite boundary, and the olivines of the olivine dolerites mostly to the hyalosiderite group.

No pleochroism has been observed in the olivines. Polysyntetic twinning of olivine was observed in a much altered dolerite.

Augite. The composition of augite in the olivine-bearing dolerites seems to be rather constant ($\gamma = 1.707$ in troctolitic dolerites, 1.710 in olivine dolerites). Owing to the "opaque" appearance of the mineral, the optical axial angle is determined only in a somewhat altered olivine dolerite: $2V\gamma = 52°—57°$.

In the olivine-free dolerite, the γ index usually is 1.712—1.717 and $2V\gamma = 54°$ but in the hypersthene-rich variety it is 1.707. $2V\gamma = 52—53°$. On the whole the range of composition of augite in the Sunnmøre dolerites is small. If estimated by Hess' method (1949, p. 634), the range would be from $Wo_{41}En_{47}Fs_{12}$ to $Wo_{39}En_{41}Fs_{20}$. The mineral has a faint green color without any perceptible pleochroism. The extinction angle, determined by the Universal stage, is variable ($c \wedge \gamma = 45 \pm 5°$) probably due to poorly developed cleavage planes.

Orthorhombic pyroxene. The orthopyroxene occurring in some olivine-bearing dolerites (II and III table 5) shows some remarkable abnormal, optical properties. It has parallel extinction, but in transparent light, without crossed nicols, it is strongly "pleochroitic" in chocolate brown colors. In most cases $\gamma > \beta > \alpha$, but sometimes $\alpha > \beta > \gamma$ (when measured by an ordinary microscope). Investigation by Universal stage, and sodium light showed that the mineral was very absorbant in one of the planes of optical symmetry. In this plane, the sodium light is almost completely absorbed in two directions perpendicular to each other and situated about 10 degrees from the principal vibration-directions. The plane of absorbtion is either (010) or (100), but it has been impossible to confirm this or make any exact discrimination by the usual methods, since the absorbtion completely dominates the other optical properties. Neither has an exact determination of the optical axial angle been possible, but it seems to be positive, and not far from 90°. The colors seem to be destroyed during metamorphism. In one grain, part of which showed the abnormal pleochroism, a questionable determination of the colored part gave $2V\gamma = 92°$ (± 3). The refractive index $\gamma = 1.705$. A very fine polysyntetic twinning, paralleling the absorbtion-plane can be seen. The extinction angle is only a few degrees. The mineral is clouded by submicroscopical, opaque inclusions, arranged in planes parallel to the absorbtion-plane.

In order to check the identity of this mineral, an X-ray powder diagram was made, and compared to another powder diagram of the optically normal and unquestionable orthopyroxene occurring in the olivine-free dolerites. The two diagrams were identical. The unit cell dimensions c = 5.20—5.22 A.

The orthopyroxene of the olivine-free dolerites is full of Schiller inclusions, which show a slight absorbing effect, γ (green), is more absorbed than α (pink). No variation of the optical properties of orthopyroxene is found within the group.

$\gamma = 1.705$, $2V\alpha = 51°$. The estimated composition is 30 per cent ferrosilite, i. e. at the division line of bronzite and hypersthene. (The nomenclature of Poldenvaart (1947, b) is adopted.) For the sake of simplicity it is named hypersthene. This normal orthopyroxene shows the same finely laminated, polysyntetic twins as the abnormal one.

Iron ores. The ore minerals are magnetite and ilmenite, with a majority of the former. Partly they occur in separate grains, but partly ilmenite is found as plates oriented after the octahedral faces of the magnetite. The ore minerals never exhibit idiomorphic crystal faces.

Spinel. A clear, green spinel occurs as rounded or irregularly formed crystals in the ore matrix or as very thin lamellae in magnetite. The spinel is rarely, if ever, observed imbedded in silicate minerals. J. H. L. Vogt (1900, p. 237) isolated and analysed spinel from an ore body at Solnørdal, found in a large dolerite lense. The analysis is reproduced in table 2.

The resulting formula is: $(Mg_{59}Fe_{39}Mn_2)(Al_{91}Fe_9)_2O_4$.

Vogt classified it as a pleonast.

Table 2.

Analysis of spinel.

	W. 0/0	Mol. quot.
Al_2O_3	61.8	6047
Fe_2O_3	4.6	576
FeO	18.1	2519
MnO	1.05	148
MgO	14.75	3658
Sum	100.3	

Formula: $(Mg_{59}\,Fe_{39}\,Mn_2)\,(Al_{91}\,Fe_9)_2\,O_4$

Secondary minerals.

Orthorhombic pyroxene. The secondary orthopyroxene is optically characterized by a high refractive index, low birefringence, and has neither color nor pleochroism. As it only occurs as small, radiating rods, mostly without cleavage cracks, with an undulant extinction, the exact determination of its optical properties is difficult. The extinction is mostly parallel to the elongation, which again is probably parallel to the c-axis, but owing to the lack of cleavage directions; it usually cannot be ascertained. The γ-index in most cases is under 1.700, but probably higher than 1.690. (It seems to vary somewhat.) In one case the crystals were large enough for determinations on the Universal stage, and the following optical axial angle figures were determined: $2V\alpha = 68°$, 72°, 77° and 78°. These data, as well as the refractive indices, indicate that the composition is not constant, but no doubt the secondary orthopyroxenes belong to the bronzite group with around Fs 20. Thus, they are poorer in iron than the primary orthopyroxenes occurring in the same rocks.

Monoclinic pyroxene. The secondary clinopyroxene is distinguished from the secondary orthopyroxene by higher birefringence, wider extinction angle, and by a faint green color. It is devoid of Schiller inclusions. $2V\gamma$ ranges from 55—65°. The refractive index γ is close to 1.700, i. e. lower than the refractive indices of the primary augites of the same rocks. It is, no doubt, a diopside, probably containing less iron and aluminium than the corresponding augite.

Garnet has a clear, red color, in transparent light faintly pink. As an isotropic mineral, it is easily recognized, even in the early coronastage. When it is imbedded in an anisotropic mineral such as plagioclase, it may sometimes look a little anisotropic, since it often is less than the thickness of the slide. The refractive index, measured in a number of rocks, ranges from 1.765 (in the olivine dolerites) to 1.800 (in an ore-rich type), probably due to the varying amounts of iron and magnesia. Some variation is also observed within the same thin-section. The garnet-corona surrounding a pyroxene and an ore mineral clustered together, is appreciably more red outside the iron ore than outside the pyroxene grain. The garnet probably belongs to the pyrope-almandite series, with subordinate amounts of grossular. Eskola (1921, p. 44) has analyzed a garnet occurring in "eclogite-hornblendegabbro" and found that the composition was: $(Fe_{61}Mg_{20}Ca_{18}Mn_{1})_3(Al_{89}Fe_{11})_2Si_3O_{12}$. The refractive index = 1.795. The present author considers this rock to be an altered derivate of the dolerite suite (cf. pp. 123—24). If this is correct, this analyzed garnet has the composition of an iron-rich member of the dolerite-garnets. If the Ca-component of garnet is constant, the index 1.765 indicates the composition $Fe_{37}Mg_{45}Ca_{18}$, according to Eskola (op. cit., p. 9).

Amphibole. The corona-amphibole must be recognized by its extinction angle and pleochroism, since no exact measurements are possible at this stage. At least two different types can be distinguished. One, occurring in the olivine-plagioclase coronas, has light yellowish green to bluish green colors. The other, in the ore—plagioclase corona, exhibits yellowish-brownish colors. The latter type is not observed at more advanced metamorphic stages. The former type, however, continues to form, but the green colors get more intense, for instance

α = light yellowish green
β = green
γ = dark green (brownish green)

A dolerite, cut by a large granite pegmatite, contains two clearly different amphiboles in the contact zone. The ophitic augite of the dolerite is converted, without change of shape, to a patchy, green amphibole. In addition, an amphibole with idiomorphic outlines is formed. The uralite has less birefringence, and weaker pleochroitic colors than the idiomorphic type, in some patches it is completely colorless. Measurements of the optical properties gave the following results:

Uralitic type: $\gamma = 1.673$, $\alpha = 1.650$, $2V\alpha = 60°$
Idiomorphic type: $\gamma = 1.683$, $\alpha = 1.650$, $2V\alpha = 80°$

Other measurements confirmed that the refractive indices given above are fairly representative. Measurements on the Universal stage, however, disclosed that the range of the optical axial angle is greater. In one olivine dolerite, which partly was much altered, the amphibole was even optically positive with $2V\alpha = 96°$ (core)—$101°$ (shell).

Biotite, likewise, seems to be of varying composition. Thus in one dolerite were found:

$\gamma = 1.650$, in the central, garnet-rich part, and
$\gamma = 1.625$ in a completely amphibolitized zone close to a cross-cutting granite pegmatite.

The pleochroism of biotite is reddish brown—dark brown, sometimes a little greenish brown.

Scapolite is observed in two localities only. It occurs as tiny crystals mostly in long strings parallel to the secondary foliation of the rocks. But it sometimes forms reaction rims around some primary mineral, for instance apatite. It is uniaxial, negative, with a rather great birefringence, probably a meionite.

Sphene, zircon, rutile, calcite and allanite are found as mineralogical rarities only. Sphene and rutile are formed at the expense of iron ores in some greatly altered dolerites, and the other minerals are likewise found only in metamorphic dolerite types, thus these minerals most probably are of secondary origin.

Chlorite is rarely found as an ordinary, secondary mineral in the dolerites, mostly it occurs in cracks or seams, which cut through all other minerals, secondary as well as primary. No doubt it is connected to a very late mineral generation of hydrothermal origin.

Table 3.

Chemical analyses of Sunnmøre dolerites.

W %	I SM 2	II SM 3	III SM 12	IV SM 106	V M 487	VI M 513	VII M 919	VIII M 922 b
SiO_2	46.89	47.62	46.80	43.45	46.26	44.62	47.56	47.61
TiO_2	1.90	1.70	1.70	0.95	2.78	1.00	2.23	1.70
Al_2O_3	17.15	18.15	17.28	13.59	14.82	14.43	17.84	17.02
Fe_2O_3	2.30	1.58	2.40	1.31	4.58	2.02	2.07	1.48
FeO	10.88	10.67	9.37	13.20	12.27	13.64	10.74	10.85
MnO	0.13	0.13	0.19	0.24	0.21	0.21	0.19	0.20
MgO	7.86	7.84	7.81	17.53	7.49	14.26	7.27	7.79
CaO	8.56	8.82	8.37	7.13	7.91	7.11	8.39	10.20
Na_2O	2.65	2·69	2.75	2.04	2.40	2.05	2.54	2.31
K_2O	0.80	0.79	1.00	0.33	0.78	0.49	0.80	0.59
H_2O-	0.02	0.05	0.09	0.02	0.08	0.10	0.10	0.06
H_2O+	0.38	0.31	1.76	0.33	0.27	0.30	0.33	0.25
P_2O_5	0.24	0.35	0.25	0.04	0.33	0.16	0.27	0.20
S	n. d.	n. d.	0.00	n. d.	n. d.	0.01	n. d.	n. d.
F	n. d.	n. d.	0.04	n. d.	n. d.	n. d.	n. d.	n. d.
Sum	99.76	100.70	99.87	100.16	100.18	100.40	100.33	100.26

Index:

I. Olivine dolerite, Vaksvik.
II. Metamorphic olivine dolerite, Vaksvik.
III. Olivine dolerite close to granite pegmatite, Vaksvik.
IV. Troctolitic dolerite, Nysetra, Ørskog.
V. Hypersthene-bearing, olivine-free dolerite, Grimstad, Ellingsøy.
VI. Troctolitic dolerite, Midtbostadstøl, Stordal.
VII. Olivine-free dolerite, Haramsgrend, Haram.
VIII. Finegrained dike in VII, Haramsgrend, Haram.

Chemical composition.

Bulk analyses.

Table 3 presents 8 analyses of dolerites from Sunnmøre. I represents an olivine dolerite. It is one of the freshest types found, although the coronas are well developed. II and III are altered olivine dolerites. The former, one of the most common rocks of the series, still preserves primary minerals and structures, but the coronas are large, and the metamorphism has even reached the cores of the primary minerals. No olivine is left, but pyroxene-pseudomorphs after olivine are numerous. III is a dark green type, occurring a few meters from a large, transgressive granite pegmatite. It is almost completely ural-

Table 4.

Normes of Sunnmøre dolerites.

	I SM 2	II SM 3	III SM 12	IV SM 106	V M 487	VI M 513	VII M 919	VIII M 922b
Or	4.80	4.65	6.05	1.90	4.75	3.00	4.80	3.55
Ab	24.10	24.15	25.25	12.70	22.15	18 25	23.10	20.95
An	32.90	35.10	32.50	26.30	28.05	28.33	35.20	34.50
Ne	-	-	-	3.12	-	-	-	-
Il	2.66	2.36	2.42	1.30	3.98	1.38	3.14	2.38
Mt	2.45	1.58	2.57	1.31	4.85	2.09	2.19	1.58
Ap	0.51	0.75	0.56	0.08	0.69	0.32	0.56	0.43
Di	6.84	5.08	6.60	6.54	8.12	4.52	4.12	12.16
Hyp	8.22	8.14	6.50	-	20.04	2.74	15.26	9.56
Ol	17.52	18.18	17.58	46.78	7.38	39.39	11.64	14.91
Sum	100.00	100.00	100.03	100.03	100.01	100.02	100.01	100.02
Ab/An	42/58	41/59	44/56	33/67	44/56	39/61	40/60	38/62
Fe/Mg	37/63	38/62	33/67	28/72	37/63	32/68	38/62	39/61

Modes of Sunnmøre dolerites.

	I	II	III	IV	V	VI	VII	VIII
Or	3	-	-	-	0.5	-	?	-
Plag.	55	34	54	-	31	60	37.5	21
Aug	2.5	2	-	-	20	?	16	?
Pr. hyp ...	-	-	-	-	10	-	2	-
Ol	2.5	-	-	-	-	20	-	-
Ore + sp ..	5	1	0.5	-	5	1	7	1
Ap	0.5	?	0.5	-	0.5	?	0.5	?
Ga	17	26	-	-	15	?	25.5	28
Di + Br ...	7	15	-	-	10*	13	8.5*	40**
Amph	-	12.5	36.5	-	?	-	-	?
Bi	7	10.5	8.5	-	8.5***	6	3.5	10***
Sum	99.5	101	100	-	100.5	100	100.5	100

Pr. hyp. = primary hypersthene. Ga = garnet. * = diopside only ** = not necessarily secondary diopside. *** = some amphibole included In plagioclas of No. VI different secondary minerals included. No mode can be given of No. IV, but originally it contained around 50 per cent of olivine and 50 per cent of plagioclase.

itized, but pseudomorphs after primary minerals and structures ar common. II and III are detached from the same olivine dolerite body and the freshest part of this dolerite cannot be distinguished from which is situated nearby, but is probably not a part of the same body IV and VI are troctolitic dolerites. Both rocks are somewhat altered. The coronas are broad, and the plagioclases are altere

Table 5.

Modes of dolerites not chemically analyzed.

	I M 137	II M 221	III M 429	IV M 431	V M 432	VI M 833	VII Bj. 7	VIII Gb III 29	IX Gb IV 8	X Hyp I 19
Or	2	7	0.5	1	0.5	0.5	-	-	-	-
Plag	51	49	43	28.5	75.5	43	55	31	42	49
Aug	20.5	12	4	4	13	8.5	23.5	14.5	30*	44
Pr. hyp . .	-	1	14	1	-	-	5.5	-	-	-
Ol	-	-	2	2.5	-	8.5	-	30.5	1	1
Ore	2	8	1	6	4	3	6	0.5	9.5	5
Ap	0.5	0.5	<0.5	<0.5	<0.5	0.9	0.5	-	0.5	0.5
Ga	11	23.**	21	34	3.5	20	-	10.5	-	-
Di + Br . .	10		12	18	3.5	11.5	-	11.5	-	-
Amph . . .	-		-	-	-	-	8.5	-	17.5	-
Bi	3		2	4.5	-	4.5	1.5	1		1
Sum	100	100.5	100	100	100.5	100	100.5	99.5	100.5	100.5

* = pigeonite included. ** = mainly garnet. VIII. Troctolitic dolerite. I, IV, V, and VI. Olivine dolerites. III. Noritic olivine dolerite. II. Olivine-free dolerite. VII. Dolerite, Gudbrandsdalen. IX and X. Dolerites of uncertain locality, supposed to be in Sunnmøre.

throughout, V and VII are taken from olivine-free dolerites, the former is rich in primary orthopyroxene and iron ores. They are both somewhat altered, but the primary structures and minerals are mostly well preserved. In the opinion of the author, only III has been subjected to metasomatic exchange of material. VIII represents the fine-grained dikes in the olivine-free dolerite All but two specimens have been analyzed by a very experienced analyst, civil engineer B. Bruun. The specimens II and IV have been analyzed by students at the Mineralogical Institute of the University. The analysis of II is not within proper limit of error, and it cannot be regarded as valid as the others. Aluminium and silica are probably a little high.

Norms and modes of the analyzed rocks are given in table 4. In table 5 modes of some other rocks are presented. The modes were calculated from one thin-section of each specimen by means of a Leitz intergrating table of modern type. In every rock the primary minerals have been replaced to some degree. In many cases the secondary minerals are too small to be safely identified, in other cases two or more minerals cannot be discriminated. It is, for example impossible to distinguish quantitatively between diopside and bronzite in the coronas and pseudomorphs after olivine. Therefore these minerals are mostly counted together. Usually it has been necessary to measure the width of the coronas, since the individual grains in them are too small to be measured separately. Frequently the smallest crystals cannot be considered at all, for instance the tiny mica crystals which form a grating pattern in plagioclase. In spite of this simplification, the calculation of modes of these rocks is a very time-consuming work. It is not worth while to make the 15 traverses necessary to get a limit of error less than 1 per cent. Therefore in most cases 8—10 transverses have been made. Larsen (1935) has shown that an error of 20 per cent may arise from the failure of a section to represent adequately the rock specimen. The present author thinks he is well within this limit for the rock-making minerals. Several tests disclosed that only small improvements are obtained through more traverses. For the accessories, however, the limit of error may be larger, especially if the minerals occur in scattered porphyric grains, in which case the limit of error may not be less than 50 per cent.

It is a peculiar fact that the norms of the olivine-free dolerite have large amounts of olivine, but not the slightest trace of this mineral is found in the rocks. At the same time, the modal anorthite-content of plagioclase is about 10 per cent lower than the normative one. A calculation shows that 5—10 per cent anorthite is sufficient to convert the normative olivinecontent of the analyzed specimen (No. VII in table 4) to hypersthene and augite. The process is more complex, however, as also the modal amount of hypersthene is less than the normative one, and thus only augite is formed in stead of olivine. If the amount of augite is 25 per cent of the total (the original amount in the olivine-free dolerite = 20—30 per cent), about 10 per cent of the Si of this augite would be replaced by Al. It is a high figure, but not higher than in some of the clinopyroxene analyses carefully selected by Hess (1949, pp. 645—66).

A variation diagram of the Larsen type (1938) is presented in fig. 12 below.

As the chemical variations in the rock suite are relatively small, and all rocks belong to the gabbroic range, where the curves often are somewhat indefinite, conclusions must be drawn with caution. The points mostly fall in smooth curves. The alkalies and lime show a slight raise with increasing acidity. Aluminium is rapidly expanding. The quantity of magnesia drops greatly from the troctolitic dolerites

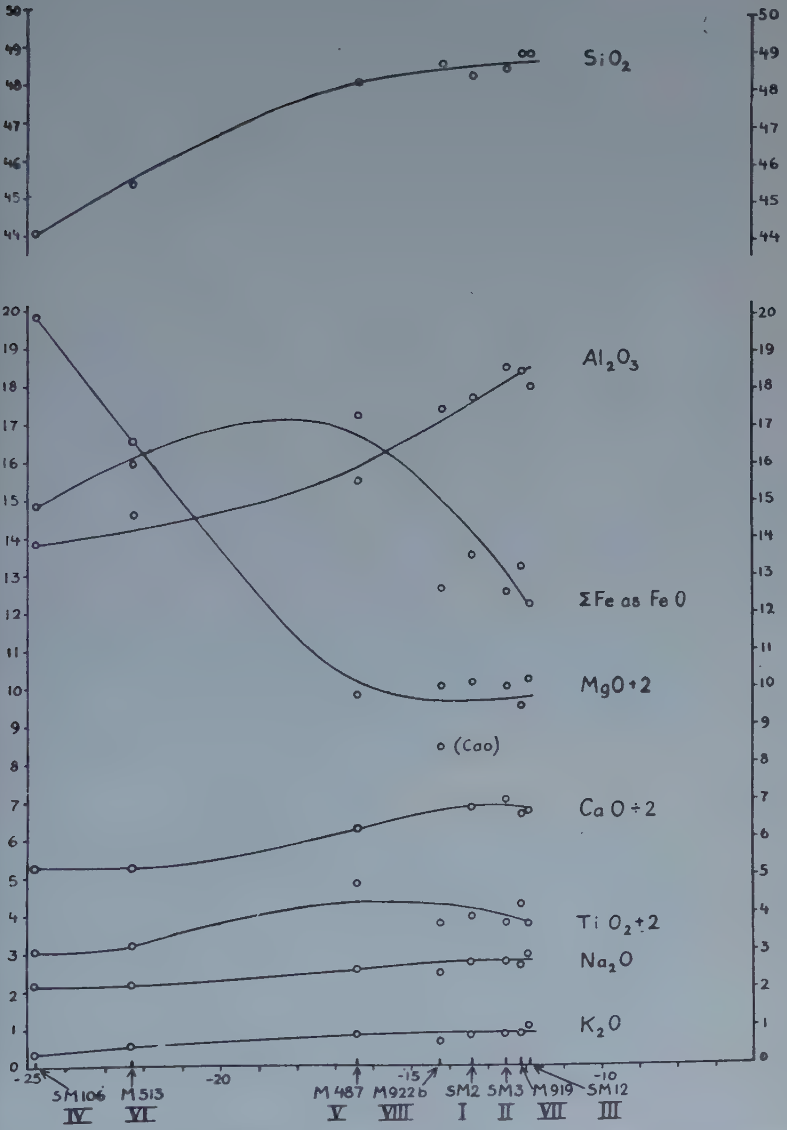


Fig. 12. Variation diagram (Larsen type) of the Sunnmøre dolerites. Index is given in table 3, p. 79.

to hypersthene dolerites, but is otherwise constant. The sum of iron increases from the troctolitic dolerites to hypersthene dolerite, then it drops rapidly. Titanium follows the trend of iron. The diagram also shows that the difference in chemical composition betweeen the olivine dolerites and the olivine-free dolerites is very small, but discloses a greater difference between the dolerite VII and the finegrained dike VIII, intersecting it, than is evident in table 3. Not only lime and titanium, but also iron in VIII fail to follow the trend shown in the variation diagram.

Trace elements.

The trace elements Cr, Ni, Co and V have been subjected to spectroscopic analysis by civil engineer S. Rutlin at Statens Råstofflaboratorium, Oslo. A quartz spectrograph was employed, with an accuracy of about 10 per cent. No specimen gave a visible chromium line, therefore no specimen contained more than 100 parts per million, and further quantitative investigation of chromium was unnecessary. The results obtained are given in table 6.

Two troctolitic dolerites, 5 olivine dolerites (3 of them more or less altered) 1 noritic olivine dolerite, 1 hypersthene dolerite, 1 olivine-free dolerite and 1 specimen of the finegrained dikes were subjected to the spectrograph. The other rocks appearing in the table were investigated for comparative purposes, and will be discussed in a later chapter.

As expected, the troctolitic dolerites are richest in Ni. It is more surprising that the Ni-content of the noritic olivine dolerite (XI) is almost as high as that of the troctolitic dolerite, which is much richer in olivine. In XI Ni probably substitutes for Mg in the (anomalous) hypersthene. The oliyine-free, hypersthene dolerite (V) however, which has almost the same quantity of hypersthene is not especially high in Ni. No chemical analysis of XI has been carried out, but the microscopical investigation of the rocks indicate that it is an earlier differensiate than V. Wager and Mitchell (1948) have been able to work out the variation of trace elements within different series of femic minerals in the Skærgaard gabbro intrusion. Table II in their
cit., p. 144) demonstrates *inter alia* that the Ni-content of
gated decreases very rapidly during the crystalliza-
for orthopyroxene are not given, but there is no

Table 6.

Trace elements of Sunnmøre and Gudbrandsdal dolerites.

	P. p. m. Cr	P. p. m. Ni	P. p. m. Co	P. p. m. V
I SM 2	<100	110	60	200
II SM 3	»	160	100	190
III SM 12	»	150	80	200
IV SM 106	»	400	100	100
V M 487	»	90	80	400
VI M 513	»	380	110	100
VII M 919	»	120	40	190
VIII M 922 b	»	130	30	300
IX SM 60*	»	120	70	250
X SM 61*	»	90	70	310
XI M 429*	»	330	100	230
XII Gb IV 8*	»	80	50	380
XIII Bj 7*	»	100	100	350
XIV Ek. I 20	»	80	100	390

Ni and Co are determined relatively to total iron, which is determined chemically except in the cases marked with *. Then the iron is inferred from the mineralogical relations.

Index of specimens I—VIII is given in table 3. IX is an olivine dolerite from Solnor, Ørskog, and X is the fine-grained, amphibolitized contact zone of this rock. XI: noritic olivine dolerite from Spjelkavik (III in table 5). XII. pigeonite-bearing dolerite of uncertain locality (IX in table 5). XIII. dolerite from Gudbrandsdal, (VII in table 5). XIV: eclogite-hornblende-gabbro from Romsdalshorn.

reason to expect it to react differently. Co shows the same tendency as Ni, but the variation is rather small. V (Vanadium) demonstrates an antipathetic relation to Ni. Since V is mainly concentrated in the iron ores, the relation is in accordance with the late crystallization of the ore minerals. It is a great surprise that the finegrained dike rock VIII, which is poor in ore, demonstrates a higher V-content than the ore-rich dolerite VII. The explanation that the latter rock has less V than expected, is not sufficient.

Petrological interpretation.

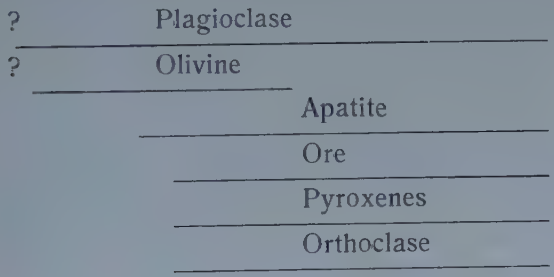
Igneous phase.

Age relations of minerals.

The textural relations do not give decisive indications of the age relations between all primary minerals, partly because the corona-formation to some degree confuses the primary conditions. Thus it cannot be ascertained whether plagioclase or olivine crystallized first. There is no doubt that these minerals crystallized before the pyroxenes, ores and orthoclase, as they exhibit idiomorphic to hypidiomorphic crystal faces, and the outlines of the minerals of the latter group always are determined by the arrangement of plagioclase and olivine. See figures 2 pl. I and 5 pl. III. However, crystallization of olivine probably continued for some time after pyroxene began to form, as the olivine-crystals enclosed in the pyroxenematrix some places are much smaller than others, (fig. 28, pl. XIV). Likewise, the crystallization of plagioclase may have been going on also at the time when the interstitial minerals formed, since plagioclase itself fills up interstices. Neither is it possible to determine from textural relations the age relation between pyroxenes, ores and orthoclase. They all occur in the same typical interstitial manner. As augite often exhibits large, ophitic crystals, which include plagioclase, olivine, and ores, the ores may, at least partly, have started crystallization before augite. Augite and hypersthene probably crystallized simultaneously. It is difficult to interpret the characteristic, crystallographic intergrowth, pictured in fig. 7, pl. IV in another way. It is no exsolution phenomenon, which the intergrowth in the other case (fig. 8, pl. IV) may be. Neither is it replacement, since the secondary orthopyroxene is otherwise. Furthermore, no other case of replacement of augite by orthopyroxene is observed. In the olivine-free, hypersthene dolerite, orthopyroxene sometimes shows a tendency toward idiomorphic growth, which is not seen in augite. This may, however, be due to a stronger crystallization power in orthopyroxene. Orthoclase may be the last mineral to crystallize, it partly seems to have developed after complete solidification of the rock, as it partly seems to replace plagioclase.

Apatite mostly exhibits idiomorphic crystal faces. However, it is concentrated in the minerals belonging to the "interstitial phase", especially orthoclase. From table 3 it is clear that P_2O_5 is more abundant in the most acid types, too. Therefore the bulk of apatite probably crystallized late, though its crystallization may have started early.

The olivine-bearing dolerites, at least, congealed rapidly, and the time-intervals between crystallization of the various minerals probably are not long. The following scheme probably covers the time sequence of the crystallization of the primary minerals fairly well:



Mechanism of intrusion.

The dolerites always occur as nearly symmetrically lense-shaped bodies elongated parallel to the structure of the enclosing gneiss. Transgressive structures connected with the intrusion of dolerites have been observed at one place only, and then on a minor scale. Even if more such features are covered or obliterated, there can be no doubt as to the generally concordant character of the dolerite intrusions. Unquestionable inclusions of the surrounding gneiss are nowhere found. Shattering or brecciation of the gneiss contact is not observed. These facts are irrelevant to any stoping-theory. No important replacement of wallrock has occurred, therefore the dolerite magma has not made its way by melting and assimilation. It is clear also, that such limited quantities of basalt magma as those corresponding to the relatively small dolerite lenses in Sunnmøre, could not assimilate large amounts of wallrock (predominantly acid gneisses) before they would deviate greatly from the original basaltic composition. Furthermore, enormous amounts of superheat of the magma are a prerequisite for any long-distance transport by assimilation.

It is theoretically possible that separate dolerite-lenses are formed by disruption of larger dolerite bodies, for instance thick sills or dikes, and that the conformability with the gneiss is tectonical, only. A number of field observations contradict this suggestion, it is probably sufficient to recall that the lenses exhibit fine-grained borders with grain-size increasing toward the center. (The grain-size is also roughly proportional to the size of the lenses.) Owing to the primarily unoriented ophitic or doleritic texture of the rocks, any mechanical deformation is readily observed. Except for some shearing along the contacts and other narrow zones, very little deformation of the dolerite bodies has taken place. Consequently, the concordant lense-shape of the dolerites must be, on the whole, an original feature.

In a dolerite body at Vaksvik, a couple of gneiss wedges are observed in the dolerite, but, since it is cut by the sea, it cannot be stated whether they are true inclusions or gneiss screens dividing the intrusion. Replacement of wallrock has not taken place to any appreciable degree. The dolerite magma must have split the gneiss along the planes of least resistence, the schistosity planes, in a period of lateral compression, and moved further until congealing took place. Very often the gneiss at the dolerite contact is more sheared and crumpled than elsewhere. Whether this is a primary or secondary feature, is not easy to decide. Similar structures are frequently observed in connection with the dunites too, and J. H. L. Vogt considered them as products of later orogenic movements (1883, pp. 137—138, see especially figs. 14 and 15). The present author thinks it possible that they, at least partly, have been caused by the intrusion.

H. Cloos contends (1936, p. 385) that concordant intrusions are typical for the middle depth-zones of orogenic belts.

Temperature of crystallization.

According to Hess (1941, p. 583) normal basaltic magmas intrude at temperatures slightly above 1100° C. He also (op. cit., p. 582) devised a method of determining the crystallization temperature. The method is based on the relation between the temperature curves of the magma and the inversion of clinopyroxene (pigeonite) to orthopyroxene. According to his diagram, orthopyroxene more iron-rich than En 70 should invert to orthopyroxene with oriented plates of clinopyroxene during cooling of the magma at a temperature of 1120° C ± 10° C.

No such orthopyroxene has been observed in the dolerites of Sunnmøre. Accordingly, the rocks should have crystallized at temperatures lower than 1100° C (invertion temperature of En 70). En inversion curve is based on experiments on natural orthopyroxenes at one atmosphere pressure, and while effect of pressure on the inversion-curve is not known, it is generally believed that pressure tends to raise the inversion temperatures. On the other hand, volatile constituents may lower the stability fields of the high-temperature phases (Walker and Polderwaart, 1949, p. 639).

The micro-crypto-perthitic orthoclase probably originated by exsolution of a high-temperature orthoclase (or sanidine). Several authors have suggested that this inversion takes place at about 700—900° C. Precise data are lacking, however.

Thus no mineralogical thermometer is found, that allows an exact determination of the crystallization-temperature of the dolerites. A rather high temperature is indicated by the abundance of exsolution phenomena, which attend the initial stage of metamorphism (brown dust of plagioclase, Schiller inclusions of pyroxene, decomposition of augite to symplectites of diopside and plagioclase, micro-crypto-perthitic orthoclase, oriented plates of ilmenite and spinel in magnetite, etc.). The general granulation of many of the pyrogenic minerals (no micro-brecciation), also indicates high isomorphic proportions not stable at the lower, metamorphic temperatures.

Because of the shearing and alteration of the contactzones, produced by the succeeding regional metamorphism, the thermal effect of the dolerite magma on the wallrock can not be evaluated, but since the different dolerite lenses are relatively small, this effect probably would not be great, anyhow.

The conclusion is that the dolerites of Sunnmøre probably crystallized at temperatures not much below those of normal basaltic intrusions, for instance at about 1000° C.

Reaction between magma and wallrock.

Since the dolerites after consolidation, together with the enclosing gneisses, have been subjected to regional metamorphism, it is not easy to find out whether or not a reaction between magma and wallrock has taken place. The heterogenity of the wallrock also causes difficulty, since the character of the gneiss ranges between amphibolite and granite, and the exact composition prior to intrusions is not known. Nor are xenoliths found in the dolerites.

The contact between dolerite and gneiss is sharp and clean, no trace of assimilation is observed. It is possible that the traces of this reaction may have been obliterated during the regional metamorphism. The dolerites probably intruded rather late in the orogenic period, however, and if any important reaction occurred, some trace would be expected, at least in the largest and best preserved dolerites.

A low content of water and other hyperfusibles in the dolerite magma may explain the lack of reaction phenomena, since they greatly facilitate contact-reactions. Before alteration, the Sunnmøre dolerites contained much less water than usually found in dolerites (cf. table 8, p. 108). During crystallization, the volatile components seem to have been concentrated in the central parts, as shown by the occurrence of dolerite pegmatites. The amphibolitization of the borderzone of the dolerites has taken place in the regional-metamorphic period, since it is attended by a marked schistosity parallel to the regional one. If amphibole was stable during the crystallization of dolerites, it ought to have appeared as a primary mineral in the dolerite pegmatite schlieren.

Whatever the original content of volatiles, the crystallizing magma has lost them to a surprisingly high degree.

Differentiation of the magma.

Since every dolerite found in Sunnmøre so far belongs to a rather basic type, all those analyzed showing a considerable amount of normative olivine, the parent magma must have been an olivine basalt type. As far as it has been ascertained, the isomorphic mineral series in the dolerites exhibit no great compositional range. The plagioclases of the olivine dolerites are moderately zoned, the nuclei contain about An 60, the shells An 50. The same range is probably found among the plagioclases of the olivine-bearing and the olivine-free dolerites. The modal composition of the troctolitic dolerite plagioclases can not be determined. The normative range of plagioclase (orthoclase-component not included) is between 67—56 per cent anorthite. Olivine probably is in the range Fa 30—45. It may be more magnesian, but the range is not appreciably greater. The composition of orthopyroxene seems to be rather constant, and the compositional range of clinopyroxene is small (cf. p. 74), the most ferrugenous augites are found in the olivine-free dolerites. The normative Mg/Fe-range of the femags is from $^{28}/_{72}$ to $^{39}/_{61}$.

The chemical variation of the two main mineral groups, the plagioclases and the femags, though rather small, follows the trends usual for a basaltic magma, according to the principles accepted at present.

As mentioned in a previous chapter, any of the separate dolerite bodies discussed possesses a rather uniform primary composition. The main differentiation must have taken place at depth (except for the ore-concentrations, which is considered in the next chapter).

The exact chemical composition of the parent magma cannot be given. Since the olivine dolerite and the olivine-free dolerite, represented by I and VII (table 3) respectively, are larger in number and much greater in bulk, than the other types, it is a reasonable guess that the parent magma is represented by one of these two types or a mixture of them. As demonstrated by table 3 and the variation diagram, fig. 12, p. 83, the chemical difference between the two types is very small. Therefore the best approximation to the composition of the parent magma probably can be reached by averaging the two analyses. In this way also, the effects of possible errors in the analyses are reduced to a minimum. The composition of the parent magma thus calculated is to be found in colomn A in table 7. As demonstrated by the textural relations, plagioclase and olivine were the first minerals to form. If one unit of a mixture, labelled B in table 7, consisting of 75 per cent olivine ($Fo_{75}Fa_{25}$) and 25 per cent plagioclase (An 67) is added to one unit of the supposed parent magma A, (both expressed in equivalent molecular percentages), 2 units of a (new) mixture is obtained, whose composition is very close to the most mafic member of the dolerite-group, the troctolitic dolerite (IV in table 3). In table 7 the relation is expressed, and for comparison the equivalent molecular percentages of IV are given.

Chemically, the differentiation of the dolerite suite of Sunnmøre may therefore be explained in the following way: The first minerals to be formed, olivine and plagioclase, settled in the lower parts of the magma (where they may have been remelted). Shortly afterwards the magma was subjected to diastrophic forces, split into different parts and injected into higher levels, where congealing took place. The rocks formed in this way have a compositional range between A and B (table 7), no rock as extremely mafic as B must necessarily be formed, and the amount of ultrabasic rocks may be small. Only a slight differentiation of the supposed parent magma (A) will lead to the two prevailing dolerite types

Table 7.

Calculation of the differentiation of the Sunnmøre dolerites.

Mol. epuiv.	A	B	$\frac{A+B}{2}$	IV (SM 106)
Si	44.0	36.5	40.3	39.2
Ti	1.5	-	0.8	0.7
Al	19.3	9.0	14.2	14.5
Σ Fe	10.3	12.5	11.4	10.9
Mg	10.5	37.5	24.0	23.7
Ca	8.7	3.5	6.1	6.9
Na	4.7	1.5	3.1	3.6
K	1.0	-	0.5	0.4
Sum	100.0	100.5	100.4	99.9

The theory does not demand that olivine crystallized before plagioclase, nor that the two minerals crystallized in the ratio 3 : 1. Because olivine is the heavier, it will sink faster.

Before any conclusions as to the mode of the differentiation process are drawn, other features beside the chemical composition, must be considered.

Mineralogically, there are few, if any real transition types between the olivine-free and olivine-bearing dolerites. Olivine is a large constituent in the latter type, but not even pseudomorphs after olivine is found in the former, although the normative content is around 10 per cent. In general, orthopyroxene does not successively take the place of olivine, as indicated by the norms (table 4, p. 80). Orthopyroxene is usually scarce also in the olivine-free types. Although the only hypersthene-rich, olivine-free dolerite yet found seems chemically to be a transition type (No. V in the variation diagram, fig. 12, p. 83), it is not intermediate between the olivine-bearing and the olivine-free, but between the troctolitic dolerites and the normal olivine dolerites. (It is a more melanocratic type than the other dolerites, the troctolitic dolerites partly excepted. The increase in the quantity of hypersthene has occurred at the expense of the plagioclase, and the ore-minerals are very abundant, therefore its peculiar position in the diagram). More than hypersthene, augite shows an antipathetic relation to olivine.

In the Skærgaard intrusion (Wager and Deer, 1939) similar relations exist between the "olivine-hypersthene gabbros" and the "middle gabbros". In this locality, the amount and composition of the minerals vary with the height in the intrusion, (increasing acidity upwards, cf. op. cit., p. 65, fig. 18). Olivine is present in the lower, but absent in the middle part of the intrusion, although the rock of the middle part contains around 10 per cent normative olivine (cf. analyses, op. cit., p. 96). Below the point of disappearance, the olivine of the Skærgaard gabbro had reached a composition close to Fa 50. (The most ferruginous olivine in the Sunnmøre dolerites is Fa 45.)

Wager and Deer (op. cit. pp. 75 and 131) think that the disappearance of olivine is due to peculiarities in the reaction relations with pyroxene, and refer to the results of Bowen and Schairer (1934, p. 209—13), but the analogy is not adequate: in the synthetic melts olivine does not cease forming as long as the melt is undersaturated. The problem is why olivine disappears before differentiation has led to a saturated magma.

The textural differences indicate that the crystallization of the two main dolerite-types in Sunnmøre took place under somewhat different conditions. The intimate connection between these two types in the field, and their similarity in kind and degree of metamorphism, do not suggest any considerable difference in time or level of intrusion. The coarser grainsize, and the lack of zoned felspar in the olivine-free dolerites indicates that is coled more slowly. It probably was richer in volatiles, which decreased the viscosity and lowered the temperature of crystallization. It is not impossible that the higher content of volatiles also indirectly influenced the stability-field of the crystal phases. The analogy with the Skærgaard intrusion, where no great textural differences exist between the olivine gabbro and the middle gabbro, does not favor this theory, however.

It might be more than a mere incidence that the olivines both at Skærgaard and in Sunnmøre, before disappearance, have obtained the same isomorphic proportions (close to Fa 50). It again raises the question of a hiatus at this point in the solid solution between forsterite and fayalite in natural magmas.

The complete lack of phenocrysts and flow structures, even in the chilled margins, and the gradual increase in grainsize towards the central parts, shows that the whole crystallization of the dolerite lenses took place in situ. This contradicts the theory of differentiation by crystal fractionation and accumulation in the magma reservoir, if remelting of the sunken crystals not occurred before intrusion. In order to avoid this difficulty, it might be postulated that the differentiation is caused by simple crystal fractionation (filter pressing). In that case the parent magma must have been of a rather ultramafic type, at least as basic as the troctolitic dolerite. Even this is not very likely. Furthermore, in order to obtain a residual magma which corresponds to the average of the two predominant types (A in table 7), it is necessary to remove one half of the original amount of magma as mineral aggregations of average composition such as B in table 7 (i. e. 75 per cent olivine and 25 per cent plagioclase), or perhaps somewhat smaller amounts of still more basic rocks. If injection and congealing took place before the differentiation had gone so far, it still is requisite that just as much mineral aggregate of average composition B must be formed, as rocks of average composition A, and the undifferentiated part of magma should result in rocks of troctolitic-dolerite composition. As the magma reservoir of the dolerites may have been bottomless, and the crystal aggregates removed from that part of magma which intruded later, this theory can neither be denied nor proved. But the quantities of the different rock types found in the field, certainly does not support the filter pressing theory: Only a few lenses composed of troctolitic dolerite were found, and none more basic, but probably more than 90 per cent of the dolerite-area consists of rocks of compositions close to A (the supposed parent magma). It seems unreasonable that the erosion, which is very deep in the area, has by chance uncovered only the acid differentiates, and a few undifferentiated rocks (according to the filter-pressing theory). This objection would be answered if it could be shown that the fractionation of the ultrabasic crystal-aggregates left by the filter-pressing, had continued to the monomineralic endstages: dunites and anorthosites. Such rocks are abundant in the inner and southern part of Sunnmøre, but not within the dolerite area proper. No transition types are found which lie between the troctolitic dolerites and the dunites, nor between anorthosites and dunites. (The additional minerals of the dunites are all femic). The dunites and anorthosites seem to be more altered and schistose than the dolerites, and although no contacts between the rocks are found, the author thinks the dolerites are younger.

J. H. L. Vogt (1910, b, p. 117) contends that the titaniferous iron ore at Rausand in Nordmøre (cf. p. 96 in the present paper) has separated from a gabbro-magma, which, again, is a segregation of a granitic parent magma. He does not, however, give any evidence or proof of an igneous origin of the surrounding granitic gneisses, nor of the supposed consanguinity of the gneisses and the gabbroic schists, within which the ore bodies occur. Neither is evidence which confirms this hypothesis found in Sunnmøre.

It is thought that the differentiation of the Sunnmøre dolerites is most satisfactorily explained by postulating a moderate fractional crystallization, accumulation and remelting of early crystals within some parts of the magma reservoir, rapidly followed by intrusion.

The finegrained dikes, occurring in the olivine-free dolerite at Haramsgrend, described on p. 58 can not have been formed by crystal fractionation or by crystal accumulation of the dolerite magma, as clearly demonstrated by the variation diagram, (fig. 12, p. 83). There is no doubt that the dikerock is closely related to the dolerite, as it is found only inside the dolerite body, and except for the elements Ti, Ca and K, it is chemically almost identical with the host. The mineralogical and structural relations of the dikes indicate that they have participated in the metamorphism of the dolerite, or been generated during it. As the dolerite body under consideration has intruded into some limesilicate gneisses, it might be suggested that they do not represents true dikes, but channelways for lime-rich solutions. However, the scarcity of hydrous minerals in the dike-rocks does not favor this suggestion. It does not seem likely, either, that they represent a magma generated by contamination of the original magma and wallrock, as such contamination should have influenced the crystallization at an earlier stage. Compared to the analyses given in table 8, the chemical composition of the dikes is more like an ordinary basalt magma than the dolerite itself! This might indicate that the dikes represents the parent magma itself, and that the dolerite represents some sort of contaminated or differentiated magma. However, the dolerite-body of Haramsgrend is identical to a great number of other dolerites, which intrude different types of wallrock. Consequently, an eventual contamination must have taken place at depth, in the parent magma. Then it is very strange that this original parent-magma should be represented by some dikes in a dolerite lense, only. No channel-way is found, during which the dolerite could get a new charge of magma from the source. Whatever the origin of these dikes, the field evidence definitely contradict this last hypothesis. In some way the genesis of these dikes must be connected to that particular dolerite, in which they occur.

The leucocratic dikes and granite pegmatites (p. 59) have no genetic connection with the dolerite magma. The same rock types also occur frequently in the granodioritic gneisses outside the dolerite area, and they are genetically connected to the regional granitization of the area. The pegmatites occurring in the dolerite body at Ellingsøy, represent some magnificant examples of replacement- formation of granite pegmatites.

Genesis of the titaniferous iron ores of dolerites.

There has been no opportunity to make a close study of the concentrations of titaniferous iron ores within the dolerites, and the following discussion is only preliminary.

It is shown that the ore minerals of the dolerites are of late, pyrogenic formation (interstitial towards plagioclase and olivine; surrounded by reaction rims), and that they are enriched in the olivine-free dolerites, some of which may be regarded as low grade ore bodies, however without any concentration of the ore minerals. In some dolerite lenses the ores are concentrated in one or more sheets or lenses, which are in some places situated in the central parts of the dolerites, in others at some distance from the contact, but never at the point of contact (fig. 13 below, reproduced after J. H. L. Vogt, 1910 a, p. 65). Some of the ore-concentrations carry rich ore, others contain plentiful gangue minerals, predominantly amphibole, with smaller quantities of garnet, biotite and oligoclase. Rarely, if ever, are primary dolerite-minerals found. The contact between ore bodies and dolerite may be either transitional or sharp.

The ore minerals are ilmenite and magnetite, the former predominantly in independent grains, but frequently also in oriented plates in magnetite. Spinel is often included in the ore minerals, sometimes as minute, oriented plates in magnetite, but usually as rounded grains. At Rausand the ore are also carries corundum (J. H. L. Vogt, 1910 a, p. 60). The same textural relation between ilmenite, magnetite and spinel is found also in the dolerite, in which no concentration of ore minerals has occurred. Chemically, the ore is characterized

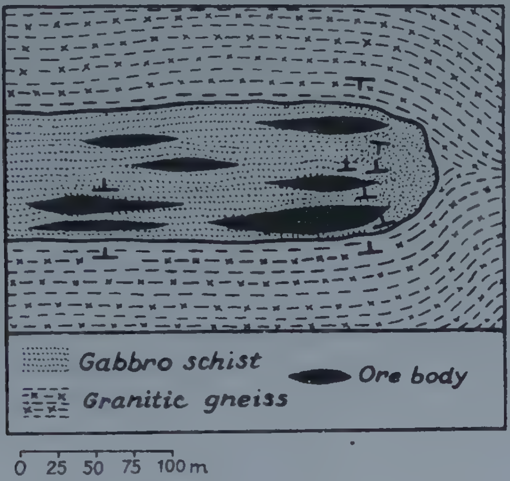


Fig. 13. Concentrations of titaniferous iron ore (Rausand type) in a "gabbro-schist" at Meisingset, Nordmøre (reproduced after J. H. L. Vogt, 1910 a, p. 65).

by a rather high content of vanadium. In the different dolerite types, this element is found in amounts roughly proportional to the content of ore minerals. The ilmenite: magnetite: spinel ratio likewise is rather constant in the dolerites and the ore concentrations.

Considering these facts, it is difficult to escape the conclusion that the ore-differentiation took place in the magmatic phase of dolerite history. In view of this, it is somewhat surprising to find that the gangue consists of secondary minerals only, and, even more surprising, that the richest ore bodies are found in some of the most altered lenses. However, it has been previously shown that the ore minerals in the dolerites are surrounded by larger reaction rims than any other mineral, olivine excepted. Though small amounts of magnetite are formed during the corona-stage of dolerite alteration, almost all pyrogenic ore is replaced by silicate minerals during the advanced metamorphism. It is therefore unreasonable to assign the ore-concentration to metamorphic processes. On the contrary, the great alteration of the lenses, in which it occurs, may partly be due to abundance of ore minerals.

Partly because of the great alteration, it is no easy task to reconstruct the fractionation process of the ore. Gravitational sinking of the heavy ore minerals has probably not occurred. In these dolerites, the ore minerals have crystallized, at a late stage, in the interstices of a 3-dimentional network of plagioclase laths, that would hamper, or prevent, sinking of minerals. The structure of the orebearing lenses (cf. fig. 13 above) does not indicate gravity stratification. Convection currents which could give rise to layers of ore minerals does not seem to have been formed (absence of flow structures).

As shown by fig. 9, pl. V, small schlieren of ore (and augite) are situated along the contacts of the dolerite pegmatites, indicating a late-magmatic origin of the ore-concentrations. Thus it is possible that an ore- and volatile-rich residual magma was formed. Another possibility which should not be disregarded, althoug no evidence is found which favors it especially, is that liquid immiscibility may occur during crystallization, if the melts of silicates and titanium-iron oxides are mutually soluble only to a limited extent.

Metamorphic phase.

The secondary processes to which the dolerites of Sunnmøre have been subjected, may be subdivided in the following way:

1. Exsolution of excess dissolved matter in the pyrogenic minerals.
2. Formation of coronas and other types of reaction rims between the pyrogenic minerals.
3. Other metamorphic phenomena, such as granulization of primary minerals, continued replacement and "Sammelkristallisation".
4. Metasomatic reactions during regional metamorphism.

It should be emphasized that the metamorphic reactions mentioned above form a continuous series. The division is solely for convenience in description and interpretation.

Exsolution.

There is no reason to believe that the dolerites of Sunnmøre have crystallized at more elevated temperatures than other dolerites. Neither is the chemical composition of the rocks especially extreme, and the primary minerals seem to be of those kinds commonly encountered in dolerites (the only exception is the abnormal hypersthene in a few olivine dolerites It therefore seems difficult to explain the exsolution features as a direct result of the primary history of the rocks.

Nevertheless, the degree and amount of exsolution in these rocks is larger than in any other dolerite suite formerly described, as far as the experience of the present author goes. Pigmented plagioclase is common in the Swedish and Norwegian hyperites, but the writer knows of no other example of augites filled to such a degree with opaque dust or Schiller inclusions that they may easily be confused with the iron ores proper. The exsolution features are more common in the olivine-bearing types than in the olivine-free ones. This is to be expected, since the olivine-bearing types have probably crystallized at more elevated temperatures, and they seem to be more rapidly chilled (finer grained, zoned plagioclase). Thus the high-temperature isomorphic ratios have been frozen, and exsolution may be initiated later. The crystallization of the olivine-free dolerites probably was a slower process, occurring at somewhat lower temperatures, and the earlier formed crystals have reacted with the melt. The crystals finally formed will have lower isomorphic ratios. The difference in exsolution-features between the two types may also have been exaggerated by the metamorphism, since the olivine-free types generally are more altered, and some exsolution-products are rapidly removed during the metamorphism.

The dolerites of Sunnmøre, like the hyperites incorporated in the Pre-cambrian gneisses of Norway and Sweden, have been subjected to a different type of metamorphism than most dolerites so far described. Their extreme exsolution-features may be ascribed to the special thermodynamical conditions during transformation of the dolerites. Resorbtion of the opaque particles takes place very quickly during metamorphism, thus they cannot reasonably be explained as metamorphic products. The secondary mineral facies indicate that the temperature and pressure during metamorphism have been rather high, allowing minerals like pyroxene to survive, but in different isomorphic proportions. Perhaps a certain amount of energy, probably mostly in form of heat, is necessary to initiate exsolution in the dolerite minerals. Macgregor (1931) demonstrates that grey-brown clouding of felspar in a number of British igneous rocks, mainly dolerites, but also some plutonic rocks, is the result of thermal metamorphism caused by later intrusions of igneous rocks. This clouding seems to be caused by inclusions of tiny, opaque crystals similar to those occurring in the felspars of the dolerites of Sunnmøre. Furthermore, in the new felspars formed by the thermal metamorphism no such inclusions occur. Thus it would seem that continued metamorphism and recrystallization remove the inclusions in this case, also. In Sunnmøre, the clouding cannot be ascribed to thermal metamorphism from younger intrusions, but it is possible that orogenic heat and movement might produce a similar effect.

As a matter of fact, exsolution should be expected in the dolerite minerals since they have crystallized at high temperatures. The reason why exsolution does not take place, is perhaps partly that the high-temperature isomorphic relations are "frozen" by quick chilling, and partly that the metamorphism which normally changes the dolerites and diabases is a low-temperature, hydrothermal type. Under such conditions the pyrogenic minerals are not stable at all, but are replaced by low-temperature minerals such as chlorite, serpentine, calcite, albite, sericite etc.

The coronas.

Synantectic reactions giving rise to coronas of different types have played an important role in the metamorphism of the dolerites of Sunnmøre. The coronas of these rocks are in many respects similar to those occurring in the hyperites of Southern Norway. In one of his last papers, Brøgger (1934) has given a magnificant description of the coronas of the hyperites, and anyone especially interested in the subject is referred to his paper.

The mineralogical composition and other features of the coronas have been presented in connection with the description of the different rock types.

The borderline between two conjugate corona rims is most often sharp, and represents the original border between the primary minerals. The best examples of this are furnished by garnet and orthopyroxene at former olivine-plagioclase contact. Garnet begins to form at the contact, and with a single exception, it only grows in the felspar area (predominantly plagioclase). Simultaneously, orthopyroxene starts growing from the same border, continuing only inwards at the expense of the olivine. This relation between host and corona mineral is demonstrated in another way, too. If a third mineral, for instance apatite, is inserted between plagioclase and olivine, the conjugate coronas split, garnet is formed on the plagioclase side, orthopyroxene on the olivine side of the third mineral.

At the ore-plagioclase contact this condition does not always hold. The border between biotite and garnet is usually irregular. Biotite also grows at the areal expense of plagioclase, and garnet, when biotite is missing, at the expense of the iron ores. Nevertheless, some of the finest examples of garnet-pseudomorphs after plagioclase are observed completely imbedded in iron ore.

Sederholm once said: "The great chemical interest of all the synantectic minerals lies in the fact that they seem to be chemical reactions written in stone." Accordingly many geologists have tried to express these reactions in exact equations. Thus Brøgger (1934) gives a number of them. In a general way these equations are useful as they show whether or not the secondary minerals can be formed by reactions between the adjacent primary minerals. The quantitative qualifications of these calculations are rather doubtful, however, since the exact composition of the synantectic minerals has not been determined. Moreover, it is very difficult quantitatively to determine the material participating in the reactions, the chemical variation of the primary minerals during the transformation, or the amount of secondary minerals formed.

A great diversity of opinions have been maintained as to the origin of the coronas. Comprehensive summaries of the views are given by Sederholm (1916) and Brøgger (1934). These theories may be grouped in the following way:

1. Late magmatic, by reactions between crystals and residual magma.
2. Post magmatic (deuteric, autometamorphic), by reactions between crystals and magmatic fluids.
3. Truly metamorphic (regional- or contact-metamorphic).

For the formation of coronas of the Sunnmøre dolerites, the author definitely rejects the first possibility. If the corona minerals represent reactions between earlier formed crystals and residual magma, the coronas of olivine, for instance, should be independent of the adjacent mineral. This is certainly not the case. During crystallization, the femic mineral series shows the usual trend of increasing iron content. If the early crystals and the residual magma react to form new crystals of the same isomorphic series, the latter ought to be more iron-rich. However, even though it has proved difficult to determine exactly the optical properties of the corona minerals, the determinations show that the corona pyroxenes are less ferruginous than the pyrogenic pyroxenes. Furthermore, the pseudomorphs after olivine, plagioclase, iron ore and hypersthene must have been formed after solidification of the rock.

Nor is there evidence favoring the second possibility, a deuteric origin. Reactions which take place at this stage of rock formation are characterized by replacement of anhydrous minerals by hydrous ones. However, the first corona-minerals to be formed in the dolerites of Sunnmøre are anhydrous. The only important exception to this rule is biotite, which belongs also to the initial stage of the corona-formation. Very often, however, biotite is absent at this stage, garnet being the only corona-mineral around iron ores. Biotite becomes more abundant in coronas and also in other places during the advanced metamorphism of the rock. Simultaneously, amphibole becomes an important corona-mineral, and the last stages of metamorphism, during which the corona-structures are obliterated, are dominated by these two hydrous minerals. The original dolerite has been a very dry rock, and in the next section it is quantitatively demonstrated that water has been added to the rock during the (regional) metamorphism. Furthermore, deuteric reactions are very common in dolerites and diabases, but the resulting mineral paragenesis and textures are very different from those exhibited by the dolerites of Sunnmøre. Thus the possibility of a deuteric origin seems to be fairly well ruled out, and even more it might be suggested that lack of water in the rocks is of importance for the corona-formation. Sufficient water makes reactions easier outside the mineral boundaries also, and thus obliterates the corona-structures more and more. The corona-structure may be especially characteristic of mineral-formation by solid diffusion.

In this connection it should be remembered that at the truly synantectic stage of corona formation a greater diversity of reaction-minerals is observed. The minerals formed in any place depend on the chemical character of the pyrogenic minerals meating at that particular place. For instance, garnet is more red (iron-rich) at the contact of ore than at the contact of pyroxene, biotite is sometimes missing as the inner corona mineral around ore. Explained in another way: the initial corona formation seems to have taken place in a closed system of micro-size.

The mineral paragenesis of the coronas indicate that the dolerites during the corona-formation have been subjected to thermodynamic conditions very different from those prevailing during the intrusion and congealing of the magma. There is nearly the same mineral paragenesis in the coronas as in the completely altered derivates of the dolerites, and there is a contineous transition from the coronites to the garnet-diopside-biotite amphibolite. It therefore seems most probable that the corona-formation in the dolerites of Sunnmøre represents the beginning of the metamorphic period and not the end of the magmatic stage.

Other metamorphic phenomena.

The following metamorphic events have been to a great extent diachronic with the corona-formation: resorbtion of exsolved particles in plagioclase and pyroxenes, granulation and alteration of these minerals, and growth of new minerals within them. At the transition-stage and the final metamorphic stages, continued replacement by predominantly hydrous minerals, and "Sammelkristallisation" of the granular crystals, also occurred.

As the opaque dust in plagioclase is rapidly resorbed in the initial period of replacement of plagioclase by the tiny non-opaque crystals, it probably participates in their formation. The resorbtion of the Schiller inclusions in pyroxene is a slower process, taking place mostly along the edges inside the coronas. Thus they may be used in the formation of garnet, amphibole, and biotite. Sometimes iron ore is also formed in the coronas, however, indicating a displacement of material. The granulation of the host minerals accelerates the removal of opaque inclusions, of course.

Granulation, which is not in this case cataclastic or protoclastic, is probably caused by the distortion of the crystal lattice during exsolution and alteration of the pyrogenic minerals. It sometimes even assumes the character of a rim reaction (cf. fig. 27, pl. XIV in which a "corona" of granular plagioclase is situated between the interstitial orthoclase and the adjacent plagioclase laths!)

It is a peculiar fact that the secondary biotite crystals outside the coronas develop preferably in plagioclase crystals, not in orthoclase. This suggests that the plagioclase during metamorphism exsolves some isomorphously held orthoclase, which may be more unstable than the primary orthoclase crystals and thus easily may be replaced by mica. The antiperthitic development in some plagioclases indicates that such exsolution has taken place. At a somewhat later stage the primary orthoclase also is replaced by biotite, and during the metamorphism all orthoclase disappears. At the final stage, many of the peculiar features resulting from synantectic reactions disappear, and the mineral composition becomes more uniform, especially through formation of hydrous minerals. The mineral reactions of the dolerites, which probably started by solid diffusion, are accelerated and completed by a hydrous fluid, coming in from outside.

By the secondary mineral reactions and structural deformation, the dolerite is incorporated in the gneiss, and if no trace of primary or coronite textures is left, the rock cannot be distinguished from other metabasites imbedded in the gneiss. The minerals are the same: amphibole, biotite, oligoclase ± diopside, garnet and quartz. It is especially interesting to find exactly the same mineral paragenesis in some of the lime-silicate-gneisses of the area, which are originally limerich sediments. The metamorphism of the dolerites must be caused by orogenic forces, since it is so closely tied to the regional metamorphism of the area. It should be emphasized that the degree of metamorphism reached is variable. Several dolerite bodies are amphibolitized in a narrow borderzone, often not more than a few meters wide. But sometimes even large bodies are thoroughly altered. To a certain extent, the degree of metamorphism is proportinal to the grainsize of the dolerites, and reversely proportional to the size of the lenses. However, almost completely altered dolerites are found close to rather fresh ones.

Metasomatism of dolerites.

The transformation of the dolerites described above, is strictly metamorphic only at the initial stage. In order to convert the dry dolerite to an amphibolite, water has to be added. Furthermore, the amount of potash in the primary dolerite is also small, and only a limited amount of biotite can be formed without introduction of this element (and water). It should be clear from the description of the rocks, that the most intensive replacement by the hydrous minerals has taken place along the gneiss contact and along transgressive granite pegmatites. In order to get a quantitative measurement of the exchanged material, an amphibolitic part of an olivinedolerite found close to a pegmatite was analyzed (III in table 3), and it was found that a considerable amount of water and some potash were added. The amount of sodium was only slightly increased. A partial analysis of the oligoclase-porphyroblastic dolerite gneiss of Hessen (p. 60) has been made, this contains 3.89 % Na_2O and 1.74 % K_2O. Thus considerable amounts of both elements have been added. In this case, no doubt, also some silica is introduced, since quartz is rather plentiful. The quartz-albite-pegmatite at Ellingsøy (p. 59) is another example of metasomatic action. No analysis has been made, but it cannot be questioned that H_2O, K_2O, Na_2O and Si_2O have been added. The analyses give very little information about the elements removed. In the specimen III ferrous iron is lower than in the unaltered olivinedolerite. Mechanical deformation has promoted the metasomatic action. At least 90 per cent of the pegmatites follow marked shearzones in the dolerites.

The analytical results confirm what might be concluded from the field relations, that the dolerites have been subjected to the same granitizing agents that have been at work in the surrounding gneisses.

Metamorphic mineral facies.

The essential minerals which are stable during the metamorphism of the dolerites are: oligoclase, garnet, diopside, amphibole, biotite, and quartz. In the corona stage, also orthopyroxene (bronzite), is formed. The disappearance of this mineral at a later stage is not a consequence of changing PT-conditions, but of a chemical homogenization. This is demonstrated by the following: In the early stage of corona-formation of the olivine-bearing dolerites, olivine reacts with plagioclase forming orthopyroxene and garnet. The garnet-corona temporarily protects orthopyroxene from reaction with plagioclase, but during the continued reactions, orthopyroxene is transformed to diopside. In the olivine-free dolerites, hypersthene in immediate contact to plagioclase is at once converted to diopside.

The only mineral facies given by Eskola, exhibiting the mineral paragenesis: plagioclase, diopside, orthopyroxene, and garnet, is granulite-facies. However, in this facies diopside and garnet should not be a stable association. In the reaction

$$\begin{aligned}\text{m. anorthite} + \text{n. orthopyroxene} \rightleftarrows \text{o. garnet} &+ \text{p. diopside}\\ &+ \text{r. quartz}\end{aligned}$$

increasing pressure will favor the reaction from left to right, since the association on the right side represents a reduction of the volume of 10—15 per cent.

Mineralogical equilibrium is not reached in the coronites. But in the central parts of the thoroughly altered dolerites, it seems to have been attained under the prevailing wapor pressure. The mineral-association of these parts of the rocks corresponds to a position in the PT-diagram of Eskola (1939, p. 345) some place between the granulite- and eclogite-facies. Since plagioclase still is a stable mineral, true eclogite-conditions are not attained within the investigated area. The same variety of granulite-facies is found as a stable, primary facies in the Heidal anorthosites (Gjelsvik, 1945, pp. 28—32).

In the border zones of the dolerites, the stable mineral association is: oligoclase, amphibole, biotite, and quartz, indicating simple amphibolite-facies. In Eskola's diagram this facies corresponds to lower PT-conditions than the variety of granulite-facies found in the central parts. If this is true, the amphibolitization of the dolerites should be a product of a late, retrograde metamorphism. However, both biotite and (two varieties) of amphibole are formed at the initial stage of corona formation. In that case the hydroxyl-bearing minerals do not seem to replace other reaction-minerals, and their formation apparently is dependent on the amount of water accessible (and in the case of biotite, also potash). Since the dolerites originally contained very little water, no great formation of hydroxyl-bearing minerals could take place, except at the contacts, where water (and alkalies) were introduced from the gneiss. It is very unlikely that different PT-conditions should exist at the contacts and in the central parts of the relatively small dolerite-lenses during the regional metamorphism (except if the regional metamorphism occurred before the dolerites had cooled after consolidation). Consequently, the temperature of metamorphism should not have been so high as to make hydroxyl-bearing minerals unstable. If the author's interpretation is correct, the metamorphic history of the Sunnmøre dolerites presents an answer to the question raised by Eskola (in his description of the granulite-facies, 1939, p. 363):

"Ob aber die Wasserarmut der Granulitfaziellen Gesteine nur auf den Temperatur-faktor zurückzuführen ist, oder ob er in erster Linie durch die Trockenheit des starren Ursprungsmaterials bedingt ist, mussen wir hier dahinstellen."

Comparison with other dolerite provinces.

Geochemical aspect.

Table 8 presents the average chemical composition of the Sunnmøre dolerites, of dolerites from other provinces, and of the main basaltic rock types of the world. The figures for the Sunnmøre dolerites, which correspond to those of the parent magma (p. 91), are calculated by averaging the figures of the two prevailing types, the olivine dolerite and the olivine-free, hypersthene-poor dolerite. The author considers this method of computation better than calculating the mean of all dolerite analyses, since the other types are so scarce, and their statistical distribution is not ascertained, yet.

As demonstrated by the table, the dolerites of Sunnmøre (A) belong to the plateau-basaltic type of Tyrrel (H), as contrasted to the "World plateau type" of Kennedy (1931), (E, F, and G). Chemically, the dolerites of Sunnmøre and the hyperites of Scandinavia (B and C) are similar and characterized by high Al-content combined with low Ca-content, and by very little H_2O. Olivine gabbros exhibit approximately the same Al-content, but are higher in Ca.

Hypothetically, the special chemical features of the Sunnmøre dolerites and of the hyperites could result from metasomatic processes during the corona-formation. However, most of the analyzed specimens from the Sunnmøre dolerites are taken from rocks in which the coronas are truly synantectic, i. e. the chemical transformations are restricted to relocation of the primary elements. Furthermore, the metasomatism, to which the rocks have been subjected, does not affect the elements under consideration, except the water content, which is greatly increased.

It is a reasonable assumption that the chemical peculiarities of the Sunnmøre dolerites are inherited from the parent magma. They

Table 8.

Average chemical composition of various basaltic provinces.

	A	B	C	D	E	F	G	H	I	J
SiO_2	47.2	46.7	46.7	47.4	51.6	51.6	52.5	47.2	47.9	46.5
TiO_2	2.1	2.2	1.3	2.2	1.6	2.7	1.0	2.4	1.4	1.2
Al_2O_3 ...	17.5	17.0	18.7	15.6	14.3	15.0	15.4	14.9	18.9	17.7
Fe_2O_3 ...	2.2	3.2	2.0	3.7	3.5	3.4	1.2	4.1	1.2	3.7
FeO	10.8	10.5	10.2	9.2	9.2	9.6	9.3	8.2	8.7	6.2
MnO	0.2	0.1	0.2	0.3	0.3	0.2	0.2	0.3	0.1	0.2
MgO	7.6	6.4	7.9	8.5	5.3	4.9	7.1	6.9	7.8	8.9
CaO.....	8.5	9.3	8.2	10.2	10.1	8.9	10.3	10.0	10.5	11.5
Na_2O ...	2.6	2.9	2.7	2.1	2.8	2.4	2.1	2.7	2.4	2.2
K_2O	0.8	0.8	0.8	0.6	1.1	1.1	0.8	0.8	0.2	0.8
P_2O_5....	0.3	0.3	0.3	0.2	0.3	0.2	0.1	0.3	0.1	0.3
ΣH_2O ...	0.4	0.6	1.1	c. a.	c. a.	c. a.	c. a.	2.1	0.5	1.0
Number of analyses	2	11	2	7	11	32	43	37	2	17

c. a. = calculated anhydrous.

Index:

A. Dolerites of Sunnmøre.
B. Hyperites of the Kongsberg-Bamble Formation, Kragerø district, SE Norway. Brøgger 1934, p. 5.
C. Swedish hyperites. Hjelmquist 1949, p. 39. Magnusson and Asserson, 1929, p. 29.
D. Hebridean olivine basalts, Walker and Poldervaart, 1949, p. 649.
E. Nonporphyric central type (N. P. C.) of Mull, Walker and Poldervaart, l. c.
F. Caledonian tholeiites and quartz dolerites of N. England and Scotland, Walker and Poldervaart, l. c.
G. Karroo dolerites, Walker and Poldervaart, l. c.
H. Average 27 plateaubasalts, Tyrrel 1921, p. 497.
I. Skærgaard gabbro, chilled marginal phase, Wager and Deer, 1939, p. 141.
J. Average 17 olivine gabbros, Daly 1910, p. 225.

are reflected in all chemical analyses, resulting in smooth curves in the variation diagram. There is no evidence of assimilation of wall-rock during intrusion and crystallization.

A question now arising is whether the basaltic substratum underlying the Sial crust of the Scandinavian peninsula corresponds to a particular "hyperite" magma. In table 9 average figures of some of the best investigated dolerite or diabase provinces of Norway and Sweden have been tabulated. (If the average figure of a province is not given in the papers quoted, the present author has calculated the average of the common types of that province.) Most of the

Table 9.

The average chemical composition of some basaltic provinces of Norway and Sweden.

	A	B	C	D	E	F	G	H	I
SiO_2	47.5	49.2	49.0	48.9	45.8	46.3	49.2	50.3	47.3
TiO_2	3.3	2.2	1.3	1.8	1.9	3.2	1.6	3.0	2.5
Al_2O_3	14.2	15.8	14.2	16.6	17.1	13.2	16.4	13.3	15.0
Fe_2O_3	4.2	3.8	2.9	3.3	2.1	4.5	2.6	6.2	3.3
FeO	9.4	6.7	8.5	9.5	12.3	12.2	8.7	8.4	11.5
MnO	0.1	0.2	0.2	0.3	0.2	0.3	0.1	0.3	0.1
MgO	6.1	4.2	7.2	4.9	6.5	5.2	6.4	4.3	6.3
CaO	8.9	7.0	11.4	7.1	8.0	9.2	9.2	7.7	8.7
Na_2O	2.8	3.9	2.7	3.4	2.7	2.7	2.7	2.7	2.5
K_2O	1.1	2.1	0.2	0.6	1.2	1.6	1.3	1.1	1.2
ΣH_2O	2.7	2.8	2.0	3.5	1.2	1.1*	1.0*	1.6	1.2
P_2O_5	0.1	0.9	0.1	0.7	0.5	0.6	0.4	0.4	0.4
Number of analyses	8	11	2	7	4	4	3	2	3

Index:

A. Diabase dikes of the southernmost coast area of Norway. Unpublished material of T. F. W. Barth.
B. Oslo-diabases. W. C. Brøgger (1933, p. 117).
C. Støren basalt. Th. Vogt (1945, pp. 466—67).
D. Øje diabase. Eckerman (1939, analyses I—VII).
E. Åsby diabase, Nordingrå region. Sobral (1913, pp. 95, 131, 133, 137).
F. Hellefors dolerite. Krokström 1936 (table XXIV, p. 229) Nos. 1, 2, 3 and 4.
G. Breven dolerite. Krokström (op. cit. B1, B2 and B3).
H. Kongadiabase. W. Larson 1932 (Nos. 255 and 307).
I. Åsby diabase, Loos-Hamra region. Eckerman (1936, pp. 307—08).
* only H_2O+.

provinces are dike intrusions, the Støren basalt and the Øje diabases, however, are extrusives. The table shows that the Norwegian basaltic rocks belong to the usual types, while some of the Swedish, especially the olivine dolerite at Nordingrå, exhibit a tendency towards the "hyperite" type. With the only exception of the Støren basalt, all provinces are characterized by a moderate to low content of lime. Although the "hyperites" (included the dolerites of Sunnmøre) can not be clearly distinguished, chemically, from the other dolerites or diabases of the Scandinavian peninsula, this does not mean that the Sima layer below the Sial crust of the two countries is of a special "hyperitic" composition. Likewise the geographical distribution of the different types indicates that the "hyperite" magma is restricted not only regionally, but also in time. Thus, close to the "hyperites" of S. Norway (B in table 8) are found the diabases, whose average composition is represented by A in table 9.

In spite of the special character of the "hyperite" magma, there is no reason to doubt that its origin is closely connected with the Sima. The reason why it is somewhat different from ordinary basaltic magma, might be sought in special geological circumstances prior to the intrusion of the rocks. One suggestion presents itself: assimilation of Al-rich rocks at depth. In Sunnmøre, the rocks surrounding the dolerites consist of two main types: acid, granodioritic gneisses, and lime-silicate gneisses. None of them can give a "hyperite" magma by contamination of the primary basaltic magma. It should be pointed out, that andesite is the common rock-type thought to be the result of contamination of basaltic magma by geosynclinal material in mountain ranges. No rocktype of suitable composition to give "hyperite" by contamination of basalt is known to be regionally distributed among the adjacent gneisses of SE Norway. In the opinion of the author, the hypothesis of assimilation does not seem very probable.

Another suggestion is that some Al-free mineral of early crystallization, for instance olivine, is withdrawn from that part of the magma which later intruded as "hyperites". In order to increase the Al-content from 15 to 18 per cent about one fifth of the original magma must be extracted as olivine by this process. However, a magma of the plateau-basaltic composition given by Tyrrel (H in table 8) gives less than 7 per cent normative olivine. Even if the total amount could be subtracted, it would be too little. The olivine dolerite of Sunnmøre (I in table 3) contains 18.4 per cent normative olivine, which, by subtraction, would produce a magma of the following composition:

SiO_2,	TiO_2,	Al_2O_3,	Fe_2O_3,	$FeO+MnO$,	MgO,
49.5	2.3	20.5	2.7	6.5	3.2

CaO,	Na_2O,	K_2O	P_2O_5
10.1	3.2	1.1	0.3

It is seen that MgO, and also FeO, would be greatly reduced. If the parent magma of the Sunnmøre dolerites should be formed in this way, the original magma must have been very high in these oxides, but very low in CaO, and it could not be compared to an

Table 10.

Trace elements of various basaltic provinces.

	P. p. m. Cr	P. p. m. Ni	P. p. m. Co	P. p. m. V	Number of analyses
Sunnmøre dolerites.					
Troct. dol. ...	< 100	390	110	100	2
Nor. ol. dol. ..	»	330	100	230	1
Ol. dol.	»	125	80	230	5
Ol. free dol ..	»	120	40	190	1
Hyp. dol	»	90	80	400	1
Skærgaard intrusion. (Wager and Mitchell 1948, p. 142).					
Gabbro picrite	1500	1000	90	120	1
Ol. gabbro ...	230	120	48	220	3
Middle gabbro	-	40	40	400	2
Garabal Hill-Glen Fyne Complex. (Nockolds and Mitchell, according to Wager and Mitchell 1948, p. 142).					
Ultrabasic	2500	700	200	100	-
Basic	300	200	70	150	-
Intermediate ..	150	80	30	100	-
Karroo dolerites. (Walker and Poldervaart (1949, p. 644 Nos. 61, 48, 17, and 5.)					
Increasing acidity of dolerites ↓ .	1400 (1750)	200 (240)	70	350	1
	350	75	30	300	2
	200	10	30	300	1
Composite rock samples. (Goldschmidt 1937, p. 662.)					
Ultrabasic	3500	3200	240	n. r.	-
Basic	350	160	80	n. r.	-
Intermediate ..	70	40	30	n. r.	-

n. r. = not recorded.

ordinary plateau-basaltic magma. There is another deficiency of this subtraction-theory: It is inconceivable that a large part of olivine could crystallize and sink before crystallization of a basic plagioclase would begin, which would retard the Al-enrichment of the residual magma.

On the other hand, a closer study of the amount and the distribution of the trace elements in the dolerites of Sunnmøre gives indications which seem to support the idea of some crystal fractionation of the original magma. In table 10 the average values of the amount of Cr, Ni, Co and V of the different types of dolerites in Sunnmøre are given, together with the same trace elements in three other provinces. In addition the average values of these trace elements (V excluded) in basic and ultra-basic rocks according to Goldschmidt are presented.

The data from the three other provinces show the earliest differentiates, the picrites or the ultrabasites, to contain relatively large amounts of Cr and Ni. But in the earliest derivatives of the Sunnmøre dolerites, the troctolitic dolerites, very little, if any, Cr is found, and the amount of Ni is much less than should be expected in a rock containing nearly 50 per cent olivine. It is generally believed that the doleritic and basaltic magmas represent the Sima layer. There is no reason to think that the basaltic substratum underlying this area, was abnormal in its content of trace elements. Consequently, the parent magma, before the formation of the Sunnmøre dolerites, must have been deprived of Cr and Ni, and then it does not correspond to the truly primary magma. Where, then, are the earliest differentiates of the primary basaltic magma? Dunites abundantly occur in the gneiss area of Sunnmøre, and they are often very rich in Cr and Ni. Partly because of the areal distribution, partly because of the difference in metamorphism, it is reasonable to assume that the dunites do not belong to the same intrusion-period as the dolerites. The dunites probably are older than the dolerites although they do belong to the Caledonian orogeny. This assumption does not contradict the theory that the dunites may represent the earliest differentiates of the primary basaltic magma. A magma within an orogenic belt may crystallize and intrude by steps. No proof of this theory, however, can be offered at present.

It seems very probable that a fractionation of early minerals (olivine, basic plagioclase, chromium minerals) from the original magma may have occurred at a period before the final differentiation and intrusion of the dolerites, (thus increasing the percentages of Al). But this is probably not the only cause of the Al-enrichment.

Comparison with the hyperites of SE Norway.

A further discussion of the relationship between the dolerites of Sunnmøre and the hyperites of the Kongsberg—Bamble formation in SE Norway will now be attempted. It is only preliminary, however, as the author has had no opportunity to make field investigations for this purpose.

Table 11.

Comparison between dolerites of Sunnmøre and hyperites of SE Norway.

	Dolerites of Sunnmøre			Hyperites of SE Norway		
	I	II	III	IV	V	VI
SiO_2	47.2	43.5	47.6	46.7	45.4	47.5
TiO_2	2.1	1.0	2.2	2.2	2.9	0.5
Al_2O_3	17.5	13.6	17.8	17.0	15.4	20.3
Fe_2O_3	2.2	1.3	2.1	3.2	3.1	0.8
FeO	10.8	13.2	10.7	10.5	13.5	6.9
MnO	0.2	0.2	0.2	0.1	0.2	0.1
MgO	7.6	17.5	7.3	6.4	5.2	9.0
CaO	8.5	7.1	8.4	9.3	8.2	11.1
Na_2O	2.6	2.0	2.5	2.9	3.4	2.6
K_2O	0.8	0.3	0.8	0.8	1.0	0.4
P_2O_5	0.3	0.1	0.3	0.3	0.4	0.1
ΣH_2O	0.4	0.4	0.4	0.6	1.0	0.7
Sum	100.2	100.2	100.3	100.0	99.7	100.0

Index:

I. Average composition of Sunnmøre dolerites.
II. Most mafic rock —»— (SM 106).
III. Most acid rock —»— (M 919).
IV. Average composition of hyperites of SE Norway.
V. Most mafic rock —»— (Bringebærkastet).
VI. Most acid rock —»— (Svaneflekken).

In table 11 the average compositions of the two rock suites are presented. In addition, the analyses of the two extreme rocks of both kinds are reproduced.

The two suites are closely related, chemically, lime and alkalies are somewhat higher in the hyperites, while aluminium is lower. The dolerites of Sunnmøre seem more differentiated, especially towards the basic end. No rock of troctolitic dolerite composition is known among the hyperites. The differentiation course of the dolerites is of normal type, but several elements in the hyperites exhibit an anomalous trend. See the table of Brøgger (1934, pp. 4—5).

1. Na, P and Ti decreases with increasing acidity.
2. K shows a sharp decline in the most acid rocks after a gentle rise from the basic towards the medium types.
3. Mg, after a slight decrease, exhibits a sharp increase towards the acid end.

These trends are so unusual that either the differentiation cannot be due to simple crystal fractionation or there must be some error in analyzing or sampling. The trend of sodium is especially surprising, as the acid differentiation product of the hyperites is said to be a series of albitic rocks (J. A. W. Bugge, 1943, p. 47).

Most of the hyperite bodies are of a fine- to medium-grained, olivine-bearing type, similar to the olivine dolerite of Sunnmøre. Primary orthopyroxene is rare. Olivine-free hyperites corresponding to the medium-to coarse-grained, olivine-free dolerites of Sunnmøre, are not reported. No chlorine-metasomatism has affected the dolerites, thus no hornblende-scapolite rocks are formed in Sunnmøre. (Scapolite is found as an accessory, secondary mineral in a few dolerites, but is a meionite.) No apatite-dikes, like those in the hyperites, are found in the dolerites.

Among the hyperites some noritic types are known, which sometimes carry nickeliferous pyrrhotite ores. The ordinary hyperites contain titaniferous magnetite ores. In the dolerites of Sunnmøre, only titaniferous magnetite ores are found.

As to mineralogical composition, considerable conformity is found among the main components of the two series. Differences exist in details, and in the accessory minerals. The plagioclase of the hyperites is more anorthite-rich, but the same brown dust is found in both cases. The almost opaquely pigmented augite, occurring in the dolerites, is not reported in the hyperites. Nor is any orthoclase found in the hyperites. Texturally the rocks seem to be nearly identical. In the coronas of the hyperites a blue-green amphibole in symplectic intergrowth with spinel constitutes the outer corona of olivine at an early stage, while garnet occurs only at a later stage. In the dolerites of Sunnmøre, garnet is formed early, and spinel is not observed as a corona mineral. The development of metamorphism is analogous in the two rock suites, but garnet does not seem to be so abundant in the hyperites as in the dolerites. The brown, mesostatic amphibole of the hyperites is not observed in the dolerites.

To sum up, great similarities, but also several differences exist between the dolerites of Sunnmøre and the hyperites av SE Norway.

Classification and nomenclature.

The Sunnmøre rock suite contains two sets of minerals: primary, or pyrogenic minerals, and secondary minerals, including the coronas. Confusion would arise if the classification of the rocks should be based on both mineral assemblages. It has often been done, and much disagreement about rock names is thereby caused. It is sufficient to refer to the discussion of the term "diabase". The author prefers to base the classification of these rocks on the primary minerals, and apply the prefix "meta"- for those which are considerably altered, but still have kept enough primary minerals and structures to make the dolerite origin unquestionable.

The first question to be decided here is whether the rocks are to be classified as plutonic or hypabyssal rocks. The textures of the rocks, especially the olivine-bearing types, are typical for dolerites or diabases, not for gabbros. The more coarsegrained, olivine-free types also exhibit these textures, but with a slight tendency towards gabbroic textures. The rocks have chilled borders, with the grain-size increasing gradually towards the central parts. The minerals show many features indicating crystallization at high temperatures, fairly rapid chilling, and subsequent exsolution. Therefore, the rocks must be classified as hypabyssal. Nothing very conclusive can be said as to the level of intrusion. Since some of the greater bodies are rather coarse-grained in the inner parts, a not too shallow level might be suggested. However, other factors than the rate of cooling affect the grainsize in a crystallizing magma chamber, for example the content of volatiles. The grainsize must be used with caution, therefore, as an indicator of the level of intrusion.

In the classification of Johannsen (1931) the rocks receive the symbol 2312 H, only the most potash-rich one corresponds to 2311 H. Most of the olivine-free dolerites lie near the division line 2212 H —2312 H.

In Shand's classification (1927) the olivine dolerites fit the class XVsM′δ, one troctolitic dolerite with normative nepheline (IV in table 4) is to be classified XWsM′δ, and the olivine-free dolerites XSsM′δ.

Texturally and mineralogically the olivine dolerites of Sunnmøre are so similar to the hyperites of SE-Norway (and likewise to those of SW-Sweden) that it would seem possible to use the name hyperite for the Sunnmøre dolerites, too. But this term has a different meaning inside and outside Scandinavia. Recently Hjelmquist (1950, pp. 32—34) has given a historical review of the term, to which the reader is referred.

Owing partly to a misstatement by Törnebohm, geologists outside Scandinavia apply the term hyperite for plutonic rocks intermediate between norite and gabbro, exhibiting a gabbroic texture. To most Scandinavian geologists the term has both a geological and a petrographical meaning. In petrographical respect the definition is somewhat vague. Törnebohm (Hjelmquist op. cit., p. 32) considered the essential minerals to be "labradorite (with brown dust), augite, hypersthene, olivine and ilmenite". Brøgger (1934, p. 2), however, considered the essential minerals to be: olivine, augite, labrador and iron ores (ilmenite with magnetite) while "rhombic pyroxene (hypersthene or bronzite) is only scarce as original, primary mineral, except in varieties shading into norites". Barth (1944, p. 26) in describing some gabbroic rocks in the Oslo region again applies the term differently "Some rocks of the gabbro family exhibit rhombic pyroxene instead of augite, they are called hyperites". Hjelmquist (op.cit., p. 34) has examined about one hundred thin-sections of "unaltered" hyperites from Western Sweden, and found that "only 43 % contained a rhombic pyroxene as primary constituent, 81 % held olivine, 30 % had both olivine and orthorhombic pyroxene. Clinopyroxene was present in 90 % of the specimens". Hjelmquist concludes (op. cit., p. 34): "To sum up, the typical hyperite is petrographically a diabasic (doleritic) rock with an ophitic or a subophitic texture, the main constituents of which are labradorite, clinopyroxene and most frequently olivine, while hypersthene is sometimes present but just as often wanting. Besides these minerals there occur ilmenite, magnetite and apatite. A most characteristic feature is the brown pigmenting of the plagioclase which gives the rock, in hand-specimens, a dark brownish black color."

The present author thinks Hjelmquist's description covers the mineralogical character of the rocks in a perfect way, and it is in good accordance with the definition of Brøgger. But it must be pointed out that this definition is very different from the definitions found in many well known textbooks of world-wide distribution (Rosenbusch, Holmes, Trøger, Teall, Johannsen, etc.). Furthermore, it might be asked what the difference is between the hyperites according to Hjelmquist's definition and plain dolerites or diabases? The present author can find only one feature: the brown dust of the plagioclase. As mentioned before, this dust is thought to be of secondary origin, and, consequently, should not be used in classification of primary rocks. Even if the pigment is regarded as a primary feature, it is of too little importance to serve as basis of a new rock class. In mineralogical classification the term hyperite is superfluous, and should be dropped before more confusion arises.

It has been shown in this paper that chemically, the hyperites are somewhat different from the common types of dolerite and diabase. The difference is rather small, however, and is manifested primarily in a greater amount of plagioclase, and, perhaps, in trifling amounts of spinel in the ore minerals.

Still the term hyperite may be useful as a combined petrographical and geological term in Scandinavian Precambrian.

The author does not like to apply the term hyperite for the Sunnmøre rocks. He simply considers them to be dolerites which have suffered a special kind of alteration. The reason for his preferring dolerite instead of diabase is mainly that the term diabase often has been used for old or altered rocks, the alteration mostly being of a lowgrade, hydrothermal type. (See the discussion of Johannsen, 1937, pp. 291—297). The term dolerite also has been used in different ways. However, it is used either for unaltered rocks, for young rocks, or for coarse-grained rocks.

The term troctolitic dolerite needs some explanation. It is used for a type containing almost 50 per cent olivine, but, contrary to the relations of picrite, plagioclase still is rather abundant, around 50 per cent. In mineralogical respect this rock is close to troctolite, but partly because of the texture, partly because it grades into the olivine-dolerites, the author thinks the term troctolitic dolerite fits better. Johannsen (1937, pp. 234—235) proposes the term Massafuerite for a rock containing more olivine than any other mineral and in addition calcic plagioclase and augite. In the dolerites of Sunnmøre plagioclase is at least as abundant as olivine. But even for the rock described by Johannsen, the present author would prefer the term troctolitic dolerite rather than massafuerite.

The troctolitic dolerite is in many respects similar to an intermediate type of the allivalite-harrisite rock on the Isle of Mull, but the plagioclase of the latter is anorthite, and its accessories are chromium minerals.

Age of dolerite intrusion.

The age-question of the Sunnmøre dolerites is intimately connected to that of the surrounding gneisses. The fresh appearance of the inner parts of the larger dolerite laccoliths, and the transgressive dolerite dike (at Ellingsøy, fig. 1, pl. I) indicate a late or post-orogenic origin of the dolerites. It has also been shown that the dolerites have been subjected to the same kind of regional metamorphism as the gneisses. Thus a late-orogenic age of the dolerite-intrusions is conceivable for the dolerites of Sunnmøre. What, then, is the age of the orogeny itself? Until some 20 years ago, the gneiss area was named: "The Romsdal Pre-cambrian region". Since then, several geologists, especially Holtedahl, have argued that the gneisses represent the central zone of the Caledonian mountain range in Norway. Holtedahl (1938, p. 21) based his assumptions on the field relations in the north-west part of the region, around Opdal, adjacent to the Paleozoic Trondheim region. A syncline of the latter region, the Surnadal syncline, the central part of which is an Ordovician basalt (greenstone) continues far into the gneiss area of Nordmøre. After a small uplift, this syncline continues on the islands outside Molde in Romsdalsfjord (C. Bugge 1934) and further westward (Gjelsvik 1950). Some lime-silicate schists accompanying these greenstones are successively transformed into gneisses, which neither structurally nor mineralogically can be distinguished from the other gneisses, situated shortly south, and enclosing a number of dolerite intrusions. Dolerite bodies are found on some small islands outside the mouth of Romsdalsfjord, in the strike direction of the greenstone-syncline, and only a few miles from the western-most greenstone-outcrop yet found. On these islands, however, no greenstone is found, only some lime-silicate-gneisses and quartz-rich schists. Whether this means that the greenstone has been displaced, or only that the rocks are more altered, has not been ascertained. The relations exhibited by the rocks south of the greenstone-syncline in Romsdalsfjord, and some other evidence presented in an earlier paper (Gjelsvik, 1950, pp. 41—44) rather strongly favor a Caledonian age of the gneiss formation.

Strand (1949), investigating the areas around Tingvold in Nordmøre, and some sections of the gneiss-region from the Caledonian rocks of North Gudbrandsdal and north-westward, seems to be of another opinion. He is able to distinguish between two types of gneisses: Paleozoic rocks, more or less granitized, and more homogeneous gneisses, which he supposes to be of Pre-cambrian origin. Furthermore, he thinks that the titaniferous iron ores of the Rausand type can be used as an indicator of Pre-cambrian origin of the enclosing gneisses. "The titaniferous iron ore deposits of Rausand and Meisingset, deposits of the Rausand type (Carstens, 1939) are situated within the areas of homogeneous gneisses referred to above (cf. Foslie 1925, p. 22). The iron ore deposits of this type must accordingly be of a Pre-Cambrian age and can serve as indicator of a Pre-cambrian origin of the parts of the gneiss area in which they occur." (Op. cit., p. 8.)

No doubt the ores at Rausand and Solnør-Sjøholt are closely related. The latter occur in somewhat amphibolitized dolerites, the former in "flasergabbro" which J. H. L. Vogt (1910 a) considered to be of igneous origin. Dolerites of the Sunnmøre suite occur not far from the Rausand Mines. There is exactly the same vanadium-bearing, titaniferous iron ore type in both places. Though the present author hesitates to agree with Strand that all titaniferous iron ores of the region are syngenetic, he thinks that most of them are. Regardless of this, it is necessary to be very critical towards the use of an intrusive rock as a proof of the age of the rocks, in which it occurs. The dolerites of Sunnmøre certainly are distributed outside the areas of "homogeneous" gneisses, but even if it could be shown that they do not occur above the homogeneous gneisses, this by no means excludes the possibility that the intrusive rock is younger than the overlying rocks. It is well known that a group of igneous rocks may be intruded below or within a certain stratum. Since they are regionally metamorphosed igneous rocks, the dolerites may have intruded at any time before the last orogenic movement ceased, in this case the Caledonian. But, as long as the age of the gneisses is not finally settled, no really safe conclusions concerning the age of the dolerites can be drawn from the relation between the dolerites and the surrounding gneisses.

If it could be shown that rocks of the dolerite suite of Sunnmøre intruded unquestionable Paleozoic rocks, their age would be settled. The author has had no opportunity, as yet, to work on this problem in the field. However, Bjørlykke (1905, p. 307) and recently Strand, have found some gabbroic intrusions in the Eocambrian sparagmites of Sel in Gudbrandsdalen, which are unlike the other intrusive rocks of the region. Strand describes these as follows:

"The gabbroid intrusives in Sparagmitian rocks in the northern part of the Sel map area present features of some interest.

In Baksidevassberget east of Høvringen a gabbroid rock occurs, which is partly finegrained like a hornfels, partly doleritic in apparance. The doleritic rock (F 29 v 488) consists of plagioclase (An 40), clinopyroxene (+2 V 45° app.), hypersthene (—2 V 70° app.), a trifle of biotite, iron ore, and kelyphitic minerals. The plagioclase is in laths of 2 mm size, the pyroxene is in the interstices between the plagioclase laths, thus representing a subophitic structure. Another gabbroid rock from the same locality (F 29v 491) is an amphibolite, which is rich in biotite in pyrphyroblasts of 2 mm size. — An Augen-gneiss (F 29v 489) occurs in close association with the gabbroid rocks, apparently with a sharp boundary, the amphibolite can be seen to contain augen of feldspar near to the boundary. The augen-gneis contains sub-rectangular porphyroblasts of microcline of 3 mm size and shows megascopically no sign of tectonisation, unlike other augen-gneisses of the same area. Microscopically it can be seen to contain a highly turbid plagioclase, and to be relatively rich in apatite. It is thus unlike the augen-gneisses of sparagmitic derivation.

A gabbroid rock in Vesleknatten north of Høvringen is probably intrusive into the Vardhø augen-gneisses, but at the north-east side it is adjacent to the micaschists with lenses of serpentine. In K. O. Bjørlykke's collection there is a subophitic gabbroid rock from this locality, very similar to the one described above, and perfectly fresh and unaltered (slide labelled Bjørlykke 1897, No. 7 in Geologisk Museum).

A rock collected by the writer at the same locality is an amphibolite rich in quartz and biotite.

Rocks intrusive into the Vardhø gneisses have also been observed at Storruste, Dovre, and epidote amphibolite of common type and an altered ultrabasic rock consisting of colorless amphibole and a chlorite mineral." (Strand 1951, pp. 75—76.)

The present author has investigated the specimens collected by Strand (F29 v 488) and Bjørlykke (Bj. 7). The augite of F 29v 488 seems to be of a titaniferous type, as it has a weak, reddish pleochroism and violet interference colors. $2V_\gamma = 42°$, $42°$. The orthopyroxene has a weak, normal pleochroism α = pink, γ = green. $2V_\alpha = 58°$. The minerals are somewhat altered, narrow reaction rims of a greenish, pleochroitic mineral, probably amphibole, are formed. Around the ore minerals there is a broad corona of this green mineral which occurs also in fractures of the plagioclase. Biotite is often formed at the expense of ore, but does not form radiating coronas. A patchy, centripetal alteration of plagioclase is observed, the secondary mineral in this case seems to be biotite. Hypersthene is rather decomposed, and contains coarse and irregular formed Schiller inclusions.

Bj. 7 is fresher. The mode of the rock is found in table 5 (No. VII) and other data are given below.

Augite: $\gamma = 1.717$, and the optical axial angle $2V_\gamma$ ranges from 30°—50°. Calculated composition: $Wo_{39}En_{41}Fs_{20}$.

Hypersthene: $\gamma = 1.710$ $2V_\gamma = 86°—93°$. The pleochroism, chocolate brown, is weak but of even more variable intensity than the abnormally pleochroitic orthopyroxene in the dolerites of Sunnmøre. Mostly $\gamma > \beta > \alpha$, but the reverse relation is occasionally observed. The calculated composition according to the refractive index is Fs_{34}.

Plagioclase: The composition of plagioclase deduced from the indices in the cleavage plane (001) is An 55 (high-temperature optics not considered).

The compositional range of plagioclase thus seems to be the same as in the dolerites of Sunnmøre. The pyroxenes are slightly more ferruginous. The secondary minerals are similar to those in F 29v 488, but they are more scarce, and the reaction rims are smaller. The pyroxenes do not contain large amounts of Schiller inclusions. Large crystals of hypersthene and augite have sometimes intergrown in the same way as described for the olivine-free dolerites of Sunnmøre.

Thus the dolerites of Gudbrandsdalen show some of the mineralogical characteristics of the dolerites of Sunnmøre. The plagioclase, however, is not appreciably pigmented, nor are the pyroxenes clouded in the same manner. The coronas are not so well developed, and the secondary minerals differ. This is probably not very significant, as the metamorphic facies must be expected to be different.

No bulk analysis has yet been made of the dolerites collected by Strand and Bjørlykke. The specimen Bj. 7 is included in the rocks investigated for trace elements in the present paper, and table 6 shows that they are similar to those of the olivine-free dolerites of Sunnmøre. More work on trace elements must be done in this case before they can safely be used as indicators of the genetic relations between the rocks. It is especially necessary to determine the content and differentiation trend of the trace elements in the different clans of eruptive rocks within the region. At present, all that can be said is that the results of the trace element determination of Bj. 7 does not contradict the theory of a genetic relation between the dolerites of Sunnmøre and Gudbrandsdalen.

Since, according to Strand, the dolerites of Gudbrandsdalen, in spite of their generally fresh appearance, in some places have suffered complete alteration to amphibolite, and probably also to augen-gneisses, these dolerites must have intruded before the close of the Caledonian orogenic movements, but probably at a late stage. The conclusion drawn by Strand in the paper above, runs as follows: "The gabbroid rocks intrusive into the sparagmites are unique within the area in the preservation of original minerals. This may be more than an incidence and may indicate that these rocks belong to a separate generation of gabbros. These gabbroid rocks are associated with amphibolites rich in biotite, which indicates a transfer of potash, and probably the augen-gneiss described above was formed from the gabbro, like the augen-gneisses in the Opdal area described by Rosenquist (1934)." The present author, being familiar with the rocks of this area, agrees with Strand as to the possibility of a separate generation of dolerite intrusions. And he would like to add that there is good evidence for a comagmatic origin of the dolerites of Gudbrandsdalen and Sunnmøre. However, more field investigation will have to be done in the intervening regions before definite conclusions as to the relationship can be drawn. However, the discovery of the (late-) Caledonian dolerites in Gudbrandsdalen, at least removes some negative evidence against the supposed Caledonian age of the dolerites of Sunnmøre.

The consanguinity of the Sunnmøre dolerites and eclogites.

According to Eskola, the eclogites in the gneisses of Nordfjord and Sunnmøre, are truly igneous rocks (1921, pp. 58—64).

In the foregoing description, it has been shown that the dolerites are altered to eclogite-like rocks. If eclogite is defined as a rock consisting predominantly of omphacite, very pyrope-rich garnet, while plagioclase is unstable, no altered dolerite within the dolerite area can be classified as eclogite. This is not a sufficient reason to disregard the possibility of a close genetic relation between the dolerites and the eclogites. The eclogite-hornblende-gabbro described by Eskola (op. cit., pp. 43—45), thought to be formed by change of facies during crystallization, is of great interest in this connection. No mode of the rock is given by Eskola, but (op. cit., p. 44):

The garnet and the clinopyroxene apparently are the most abundant constituents, after which follows plagioclase, hornblende, biotite, ilmenite. Apatite and rutile are minor constituents." Concerning the relations between the minerals, and the origin of the rock, Eskola writes (p. 45):

"Probably garnet and pyroxene were the first minerals to crystallize out of this rock, and it seems that the hornblende and plagioclase were formed later at the expense of the former. This change apparently took place at the last stage of consolidation.

The evident resorbtion of the earliest minerals, however, was hardly a phase of a normal process of crystallization, but rather due to changes in the attendant physical conditions during that process. Or perhaps there was a refusion of a true eclogite already crystallized, and re-consolidation of the hornblende-plagioclase mass now appearing as a mesostasis.

We arrive at the conclusion that the eclogite-hornblende-gabbro of Romsdalshorn contains two sets of minerals originated at different stages of the rock development and under different conditions. The earlier one belonged to the eclogite-facies while the later represents the typical hornblende-gabbro-facies."

The type-specimen of the rock, which was collected not far from some meta-dolerites, shows rather coarse grainsize, and only doubtful relic-structure, but the general appearance is very like that of the completely altered dolerites. Since the mineral assemblage also is the same, little doubt is left as to the consanguinity of the rocks. The chemical composition (op. cit., p. 43), is not very different from that of the dolerites. The deviations may partly be due to peculiar primary composition (for instance excessive amounts of iron ores), but probably some exchange of material has occurred during metamorphism (enrichment of potash). The trace elements of the rock, (XIV in table 6, p. 85) agree with the dolerite figures, especially with the ore-rich types.

Eskola does not discuss the possibility of a metamorphic origin of the rock, and his conclusion, given above, is not attended by any proofs. In a later chapter (op. cit., pp. 78—80) he apparently is more doubtful:

"In the previous discussion I have regarded the structural evidence as sufficient to decide whether an eclogite has undergone a posterior alteration into the amphibolite facies, or has been brought under the condition of the latter before perfect consolidation, and I believe the evidence to be convincing for the former alternative, when symplectites occur, and for the latter, when brown hornblende filling the interstices, or large and anhedral individuals of plagioclase as a mesostasis, are present. But a granular hornblende-plagioclase-mass might also be taken for metamorphic, and it may be difficult to know exactly the mode of origin."

In the rock under consideration, symplectites occur, which, according to Eskola himself, should be a criterion of metamorphic origin, and he also admits that a granular plagioclase-hornblende mass may be a metamorphic feature. Thus nothing in his description contradicts the theory of a metamorphic mode of origin.

In the opinion of the present author, the rock is not an altered eclogite, but an altered dolerite in transition to eclogite. Accordingly, some of the eclogites in the southern part of Sunnmøre may be altered dolerites.

The metamorphism of the dolerites within the region throws a new light on the genetic problems of the eclogites of Norway.

Summary of conclusions.

Igneous period of rock formation.

1. Mechanism of intrusion.

Because of the generally concordant form of the dolerite bodies, the lack of crosscutting feeding channels, and the absence of stoped blocks of wallrock, it is thought that the magma, in a period of lateral compression, was pressed in between the schistosity planes of the gneiss (the planes of least resistance), and moved along these until congealing took place.

2. Differentiation of magma.

The differentiation of magma has led to the following rock-types: troctolitic dolerite, olivine dolerite, noritic olivine dolerite, hypersthene-bearing, olivine-free dolerite, and titaniferous iron ore. With the exception of the ore, all types form individual bodies of homogeneous composition. Therefore the differentiation has taken place at the depth. No great differentiation has occured, SiO_2 ranges between 43.5 and 47.5 per cent by weight, cf. table 3. The oxides follow gently curved lines in a variation diagram (fig. 12, p. 83). The textures demonstrate that plagioclase and olivine crystallized before the other principal constituents. A chemical calculation shows that the most extreme mafic dolerite formed, the troctolitic dolerite, is obtained by adding one unit of the supposed parent magma to one unit of a crystal aggregate consisting of 75 per cent olivine (Fa 25) and 25 per cent plagioclase (An 67). Thus it is thought that the differentiation was brought about by a moderate crystal fractionation, combined with local accumulation (and probably remelting) of early crystal phases, immediately followed by intrusion.

Of especial petrological interest is the absence of olivine in a large group of dolerite, although the rocks correspond to a magma with 10 per cent normative olivine. The same is observed by Wager and Deer at the Skærgaard intrusion. These authors explain it as a result of peculiar reaction relations with pyroxene in a magma undergoing crystal fractionation. They refer to the results of Bowen and Schairer on synthetic melts. This explanation is not correct however, since in the synthetic melts olivine does not cease forming as long as the magma is undersaturated.

In Sunnmøre, considerable textural difference is found between the olivine-bearing and olivine-free dolerites, which might indicate crystallization under somewhat different physical conditions. A higher content of volatiles in the magmas of the olivine-free dolerites could possibly influence the stability field of the crystal phases. This theory, however, is found to be inadequate, since no such textural difference is found between the corresponding rock types in the Skærgaard intrusion.

Since the olivine, both at Skærgaard and in Sunnmøre, has, before disappearance, reached a composition close to Fa 50, the phenomen again raises the question of a hiatus in the solid solution series of olivine in *natural* magmas.

3. Genesis of the titaniferous iron ore.

The iron ore occurs in lenticular bodies, conformable with the structure of the dolerites, within which it is found, usually in the central parts, rarely close to the borders.

The ore minerals are of magmatic origin, and were formed during a late, pyrogenic stage. They have not been concentrated by gravity accumulation. The possibility of layering by convection currents are rendered rather improbable by the lack of flow structures. Two possibilities are suggested: either formation of a residual magma, rich in ores (and volatiles), or liquid immiscibility during crystallization.

Metamorphic phase of rock formation.

The metamorphism of the dolerites has been a continuous process, but it can be described in the following, partly overlapping, steps:

1. Exsolution of pyrogenic minerals.

This process especially affected plagioclase and augite in the olivine-bearing dolerites. The former is so clouded by submicroscopic, brown dust that it looks black in the rock surface, while in augite submicroscopic iron ore (probably magnetite) makes the host mineral look almost opaque. Orthoclase is altered to crypto-micro perthite, etc.

No features are found, indicating that the extreme exsolution is a direct result of the primary history of the dolerites. Nor is it reasonable that the exsolved particles should be metamorphic products, since they are most prominent in the freshest specimens, and are rapidly resorbed during metamorphism. Most probably the exsolution is due to special thermo-dynamic conditions during the regional metamorphism of the relatively rapidly chilled dolerites. Orogenic heat probably initiated the reaction.

2. Formation of coronas and other reaction rims.

Reaction rims between the felspars, especially plagioclase, and the colored minerals have played an important (perhaps the most important) role in the transformation of the dolerites.

Since the formation of coronas is dependent on the adjacent minerals, and the reaction products are more magnesian than the pyrogenic minerals of the same isomorphic series, they are not late magmatic products. The pseudomorphs after olivine, plagioclase, iron ore, and hypersthene, which are the ultimate results of some rim reactions, clearly demonstrate that the reactions have taken place after consolidation of the rocks. No evidences favoring a deuteric origin are found, either. The first minerals to form are typically anhydrous (garnet, bronzite, diopside), biotite being the only significant exception to the rule.

The author interprets the corona-formation of these rocks as a truly metamorphic (regional-metamorphic) process, and suggests that it is especially characteristic of mineral formation by solid diffusion. The initial corona reactions seem to have taken place in a closed system of micro-size.

3. Other metamorphic reactions.

Resorbtion of the exsolved particles, granulation of pyrogenic minerals, and growth of new minerals within them, were, to a great extent, diachronic with the formation of the coronas. The granulation is probably not a cataclastic feature, but is caused by the distortion of the lattices during exsolution and alteration of the pyrogenic minerals.

At a more advanced corona-stage, hydrous minerals (amphibole and biotite) begin to be abundant among the rim minerals, and in the final stages of metamorphism they are predominant, replacing pyrogenic minerals as well as early corona minerals. "Sammelkristallization" also occurs, and the final product of metamorphism is a crystalloblastic, amphibolitic rock, including biotite, garnet and diopside. The same mineral paragenesis is encountered in the regional-metamorphic, mafic rocks of the region, especially the lime-silicate gneisses. Furthermore, the secondary schistosity developed in the dolerites, is conformable to the general gneiss structure. The author, therefore, considers the metamorphism of the dolerites to be of orogenic origin.

4. Metasomatism.

The metamorphism of the dolerites is attended by exchange of material, most intensive along the contacts of gneiss and granite pegmatite. In these places only hydrous mafic minerals are formed. Analyses demonstrate that water, alkalis (especially K) and probably some SiO_2; are added, but do not give definite evidence about the elements removed. Mechanical deformation has promoted the metasomatic action. Some inquestionable examples of formation of granite pegmatite in dolerite by metasomatism are described.

The same granitization is very characteristic of the surrounding gneisses. Since it is closely tied to the regional metamorphic period, it presents more evidence of orogenic origin of the alteration of the dolerites.

Metamorphic mineral facies.

The secondary mineral assemblage of the dolerites corresponds to the granulite facies of Eskola. However, in this facies diopside and garnet should not be in stable association. In the Sunnmøre meta-dolerites, the two minerals are undoubtedly in equilibrium. This facies probably is a higher pressure-facies than the granulite facies, and is related to the eclogite facies.

In the border zones of the meta-dolerites, the minerals indicate amphibolite facies. This is probably not due to any retrograde metamorphism. The formation of hydrous minerals seems to be dependent on the available amount of water, only. (In the case of biotite, also K, of course.) Since it is unlikely that the PT-conditions at the contacts and in the central parts of the dolerite-lenses would be different during the regional metamorphism, it may indicate that the H_2O deficit in the granulitic rocks is not necesarily a result of the PT-conditions during metamorphism.

Comparison with other dolerite provinces.

Table 8 demonstrates that the Sunnmøre dolerites belong to the plateau-basaltic type of Tyrrel, (as contrasted to the world plateau type of Kennedy), and that they are chemically almost identical with the hyperites of SE Norway and SW Sweden. They differ from the typical plateau-basalts by higher Al, combined with low Ca, and by very low H_2O. These chemical characteristics cannot be due to metasomatic action during the metamorphism, since the elements under consideration were not especially effected, except for water, which was greatly increased. No assimilation of wallrock during intrusion and crystallization took place. The chemical peculiarities are inherited from the parent magma of the dolerites. It is generally believed that the parent magma of basalts and dolerites corresponds to the Sima layer. Table 9, which presents the average composition of a number of basaltic provinces in Norway and Sweden, does not indicate that the Sima layer underlying the Scandinavian peninsula is of a special "hyperitic" type.

The reason why the Sunnmøre dolerites, like the hyperites, differ chemically from ordinary plateau-basalts, must be sought in special circumstances prior to intrusion. In the author's opinion, the hypothesis of assimilation of Al-rich rocks, does not seem to be probable. No rock type of suitable composition to give "hyperite" by contamination of basalt is known to be regionally distributed among the adjacent gneisses in Sunnmøre, nor in SE Norway and SW Sweden. Removal of early olivine (forsterite), from the crystallizing magma, would produce a residual magma enriched in Al. However, very large amounts of olivine (3 times the normative olivine amount of the plateau-basalt of Tyrrel) had to be subtracted, in order to raise the Al-content from 15 to 18 per cent. Calculation shows that if the parent magma should produce a "hyperitic" residual magma in this way, its original composition would have to be very different from that of an ordinary plateau-basalt.

Although subtraction of early differentiates cannot satisfactorily explain the whole Al-enrichment, a comparison of the distribution of trace elements of the Sunnmøre dolerites with those of other basaltic provinces strongly indicates that it has occurred to some extent. Thus even the earliest derivatives of the Sunnmøre dolerites, the troctolitic dolerites, containing about 50 per cent olivine, are devoid of Cr, and relatively poor in Ni. Since there is no reason to believe that the basaltic substratum underlying this area was abnormal in the content of trace elements, the parent magma must have been deprived of Cr and some Ni, before formation of the Sunnmøre dolerites.

Since the dolerite magma intruded under orogenic conditions, it might have crystallized and intruded by steps. It is even possible that the dunites of Sunnmøre, most frequently situated to the south of the dolerite area, represent earlier derivatives of the dolerite magma.

Classification and nomenclature.

In the classification of Johannsen, the rocks receive the symbol 2312 H, and only those richest in potash correspond to 2311 H. In Shand's classification the olivine-bearing dolerites fit the class XVsM′δ, the troctolitic dolerite with normative nepheline: XWsM′δ, and the olivine-free dolerites: XSsM′δ.

The author considers the rocks to be hypabyssal rather than plutonic rocks, and prefers to name them dolerites. Since they are so similar to the hyperites of the Scandinavian peninsula, they could also be called hyperites. But this term is used in different meanings inside and outside Scandinavia, and has caused great confusion. Therefore the author proposes to drop the term in the petrographic classifications.

Age of the dolerite intrusion.

Since the dolerites are affected by the regional metamorphism, they cannot be younger than the last orogeny of the region, the Caledonian one. The gneisses which previously were believed to be of Pre-cambrian age, are by many geologists now considered to be Caledonian rocks. The present author favors the later opinion. The fresh appearance of many dolerites suggests a late orogenic origin. However, as long as the age question of the gneisses is not definitely settled, no really safe conclusions can be drawn from this relation.

The present author finds some evidence for a co-magmatic origin of the Sunnmøre dolerites and some dolerites in Gudbrandsdal, (to the east of Sunnmøre), which intrude Sparagmitic rocks, and thus are definitely Caledonian intrusives, probably of late orogenic age.

The consanguinity of the Sunnmøre dolerites and eclogites.

According to Eskola, the eclogites in the gneisses of Nordfjord and Sunnmøre are truly igneous rocks. The present author thinks that at least one of the eclogite-types described in his paper, the eclogite hornblende-gabbro, is a completely altered dolerite. Eskola thought that the two sets of minerals in the rock originated by a change of facies during crystallization. The rock, from which the type specimen was detached, occurs at a distance from some metadolerites, and nothing in Eskola's description contradicts the possibility of a metamorphic origin. Thus the metamorphism of the Sunnmøre dolerites sheds new light on the genetic problems of the eclogites of Norway.

References.

Andersen, O., 1926: Feltspat I. Norges Geol. Undersøkelse nr. 128 A, pp. 1—142.

Asserson, G., and Magnusson, N. H., 1929: Beskrivning till kartbladet Nyed. Sveriges Geologiska Undersökning. Ser. Aa. N:o 144, pp. 1—109.

Barth, T. F. W., 1931: Permanent changes in the optical orientation of feldspars, exposed to heat. Norsk Geol. Tidsskrift. Bd. 12, pp. 57—72.

— 1944: Studies on the igneous rock complex of the Oslo region. II. Systematic petrography of the plutonic rocks. Norske Vidensk.-akad. skr. I. Mat.-Naturv. kl. no. 9, pp. 1—104, 1945.

— and Oftedahl, Chr., 1946: High-temperature plagioclase in the Oslo igneous rocks. Am. Geophys. Union Trans. vol. 28 no. 1, pp. 102—104, 1947.

Bjørlykke, K. O., 1905: Det centrale Norges fjeldbygning. Norges Geol. Undersøkelse no. 39, pp. 1—595.

Bowen, N. L. and Schairer, J. F., 1934: The system MgO—FeO—SiO_2. Am. Jour. Sci. 5. ser. vol. 29, pp. 151—217, 1935.

Brøgger, W. C., 1879: Über Olivinfels von Søndmør. Neues Jahrb. 1880. II. pp. 187—192.

— 1933: Die Eruptivgesteine des Oslogebietes. VII. Die chemische Zusammensetzung der Eruptivgesteine des Oslogebietes. Norske Vidensk.-akad. skr. I. Mat.-Naturv. kl. no. 1, pp. 1—141, 1934.

— 1934: On several Archæan rocks from the south coast of Norway. II. The south Norwegian hyperites and their metamorphism. Norske Vidensk.-akad. skr. I. Mat.-Naturv. kl. 1934 no. 1, pp. 1—421, 1935.

Bugge, C., 1905: Kalksten og marmor i Romsdals amt. Norges Geol. Undersøkelse no. 43, Aarbog for 1905. VI, pp. 1—37.

Bugge, C., 1934: Grønne trondhjemsskifre på øyene ved Molde. Norsk Geol. Tidsskr., Bd. 14, pp. 167—175, 1935.

Bugge, J. A. W., 1943: Geological and petrographical investigations in the Kongsberg-Bamble Formation. Norges Geol. Undersøkelse Nr. 160, pp. 1—150.

Chudoba, K. F., und Frechen, J., 1943: Der Einfluss der Temperatur auf die Beziehung zwischen Optik und Chemismus der Olivine. Neues Jahrb. Abt. A, H. 6, pp. 91—106.

Cloos, H., 1936: Einführung in die Geologie.

Daly, R. A., 1910: Average chemical compositions of igneous-rock types. Am. Acad. Arts Sci. Proc. vol. 14, no. 7, pp. 211—240.

Deer, W. A., and Wager, L. R., 1939: Geological investigations in East Greenland. Part III. The petrology of the Skærgaard intrusion, Kangerdlugssuaq, East Greenland. Meddelelser om Grønland, Bd. 105 no. 4, pp. 1—335.

Eckerman, H. von, 1936: The Loos-Hamra region. Geol. Fören. Stockholm Förh. Bd. 58, H. 2, pp. 130—343.

— 1939: A contribution to the knowledge of the Öje diabase. Geol. Fören. Stockholm Förh. Bd. 61, H. 2, pp. 177—192.

Emmons, R. C., 1943: The Universal Stage. Geol. Soc. America Mem. 8, pp. 1—204.

Eskola, P., 1921: On the eclogites of Norway. Norske Vidensk.-akad. skr. I. Mat.-Naturv. kl. no. 8, pp. 1—118.

— Barth, T. F. W., Correns, C. W. and —, 1939: Die Entstehung der Gesteine.

Frechen, J., und Chudoba, K. F., 1943: Der Einfluss der Temperatur auf die Beziehung zwischen Optik und Chemismus der Olivine. Neues Jahrb. Abt. A, H. 6, pp. 91—106.

Gjelsvik, T., 1945: Anorthosittkomplekset i Heidal. Norsk Geol. Tidsskr. Bd. 26, pp. 1—58, 1946.

— 1950: Oversikt over bergartene i Sunnmøre og tilgrensende deler av Nordfjord. Norges Geol. Undersøkelse nr. 179, pp. 1—45, 1951.

Goldschmidt, V. M., 1937: The principles of Distribution of Chemical Elements in Minerals and Rocks. Chem. Soc. London Jour., pp. 655—673.

Hess, H. H., 1941: Pyroxenes of common mafic magmas. Am. Mineralogist, vol. 26, pp. 515—535, 573—594.

— 1949: Chemical composition and optical properties of common clinopyroxenes. Am. Mineralogist, vol. 34, pp. 621—666.

Hjelmquist, S., 1950: The titaniferous iron-ore deposit of Taberg in the south of Sweden. Sveriges Geol. Undersökning. Ser. C, no. 512, pp. 1—55.

Holmes, A., 1918: The basaltic rocks of the Arctic region. Mineralog. Mag. XVLLI, pp. 180—223.

Holtedahl, O., and Bailey, E. B., 1938: Northwestern Europe. Caledonides. Regionale Geologie der Erde, Bd. 2, Abschnitt II. pp. 1—76.

— 1944: On the Caledonides of Norway. Norske Vidensk.-akad. skr. Mat.-Naturv. kl. no. 4, pp. 1—31.

Johannsen, A., 1931: A descriptive petrography of the igneous rocks, vol. I, pp. 1—267.

— 1937: A descriptive petrography of the igneous rocks, vol. III, pp. 1—360.

Kemp, J. F., 1910: A handbook of rocks for use without the microscope. 2 ed., pp. 1—185.

Kennedy, W. Q., 1931: VIII. The parent magma of the British Tertiary province. Geol. Survey Great Britain, Summary of progress for 1930, part 2, pp. 62—73.

Koehler, A., 1940: Die Abhängigkeit der Plagioklasoptik von vorangegangenen Wärmeverhalten. Min. pet. Mitt., vol. 53, pp. 24—49, 1942.

— 1949: Recent results of investigations on the feldspars. Jour. Geology, vol. 57, pp. 592—599.

Krokström, T., 1932 a: The Breven dolerite dike. Geol. Inst. Uppsala. Bull. vol. XXIII, pp. 243—330.

— 1932 b: On the ophitic texture and the order of crystallization in basaltic magmas. Geol. Inst. Uppsala, Bull. vol. XXIV, pp. 197—216.

— 1936: The Hällefors dolerite dike and some problems of basaltic rocks. Geol. Inst. Uppsala Bull., vol. XXVI, 1937, pp. 113—263.

Larsen, E. S., and Miller, F. S., 1935: The Rosiwal method and the modal determination of rocks. Am. Mineralogist, vol. 20, pp. 260—273.

— 1938: Some new variation diagrams for groups of igneous rocks. Jour. Geology, vol. 46, pp. 505—520.

Larson, W., 1932: Chemical analyses of Swedish rocks. Geol. Inst. Uppsala. Bull. 24, pp. 47—196.

MacGregor, A. G., 1931: Clouded feldspars and thermal metamorphism. Mineralog. Mag., vol. 22, pp. 524—538.

Magnusson, N. H., and Asserson, G., 1929: Beskrivning till kartbladet Nyed. Sveriges Geol. Undersökn. Ser. Aa, N:o 144, pp. 1—109.

Miller, F. S., and Larsen, E. S., 1935: The Rosiwal method and the modal determination of rocks. Am. Mineralogist, vol. 20, pp. 260—273.

Mitchell, R. C., and Wager, L. R., 1948: The distribution of Cr, V, Ni, Co, and Cu during the fractional crystallization of a basic magma. Report of the eighteenth Session, Great Britain, 1948, part II, pp. 140—150.

Oftedahl, Chr., and Barth, T. F. W, 1946: High-temperature plagioclase in the Oslo igneous rocks. Am. Geophys. Union, Trans., vol. 28, no. 1, pp. 102—104, 1947.

Poldervaart, A., 1947 a: Subcalcic ferroaugite from Mount Arthur, East Griqualand. Mineralog. Mag., vol. 28, pp. 159—163.

— 1947 b: The relationship of orthopyroxene to pigeonite. Mineral. Mag., vol. 28, pp. 164—172.

— and Walker, F., 1949: Karroo dolerites of the Union of South Africa. Geol. Soc. America Bull., vol. 60, pp. 591—706.

Reusch, H. H., 1877: Grundfjeldet i Søndre Søndmør og en del av Nordfjord. Norske Vidensk.-selsk. Forh. 1877, no. 11, pp. 1—18, 1878.

Reusch, H. H., 1883: Nye oplysninger om olivinstenen i Almeklovdalen og Sundalen på Søndmøre. Norske Vidensk.-selsk. Forh. 1883, no. 1, pp. 1—18, 1884.

Schairer, J. J., and Bowen, N. L., 1934: The system $MgO—FeO—SiO_2$. Am. Jour. Sci. 5. ser., vol. 29, pp. 151—217, 1935.

Shand, S. J., 1927: Eruptive Rocks. 1st ed.

Sederholm, J. J., 1916: On Synantectic Minerals and related Phenomena. Comm. Geol. Finlande, Bull. no. 48, pp. 1—148.

Seifert, H., 1941: Über ein basaltisches Gestein der Roccamonfina. Neues Jahrb., Beil. Bd. 77, pp. 277—336.

Sobral, J. M., 1913: Contributions to the geologogy of the Nordingrå region.

Strand, T., 1949: On the gneisses from a part of the North-Western gneiss area of Southern Norway. Norges Geol. Undersøkelse nr. 173, pp. 1—45.

— 1951: The Sel and Vågå map areas. Norges Geol. Undersøkelse nr. 178, pp. 1—117.

Tomkeieff, S. I., 1939: Zoned olivines and their petrogenic significance. Mineralog. Mag., vol. 25, pp. 229—251.

Tyrrel, G. W., 1921: Some Points in Petrographic Nomenclature. Geolog. Mag., vol. LVIII, pp. 494—502.

Vogt, J. H. L., 1883: Olivinstenen i indre og søndre Søndmør. Nyt mag. naturvidensk. Bd. 27, pp. 125—153.

— 1900: Weitere Untersuchungen über die Ausscheidungen von Titaneisenerzen in basischen Eruptivgesteinen. Zeitschr. prakt. Geologie, Jahrg. 1900, pp. 233—242, 370—382.

— 1910 a: Über die Rødsand Titan-eisenerzlagerstätten in Norwegen. Zeitschr. prakt. Geologie, Jahrg. 18, pp. 59—67.

— 1910 b: Norges Jernmalmforekomster. Norges Geol. Undersøkelse nr. 51, pp. 1—225.

Vogt, Th., 1945: The geology of the Hølonda-Horg district, a type area in the Trondheim region. Norsk Geol. Tidsskr. nr. 25, pp. 449—528.

Wager, L. R., and Deer, W. A., 1939: Geological investigations in East Greenland. Part III. The petrology of the Skærgaard intrusion; Kangerdlugssuaq, East Greenland. Meddelelser om Grønland, Bd. 105, no. 4, pp. 1—335.

— and Mitchell, R. C., 1948: The distribution of Cr, V, Ni, Co, and Cu during the fractional crystallization of a basic magma. Report of the Eighteenth Session, Great Britain, 1948, Part II, pp. 140—150.

Walker, F., and Poldervaart, A., 1949: Karroo dolerites of the Union of South Africa. Geol. Soc. America, Bull., vol. 60, pp. 591—706.

Winchell, A. N., 1933: Elements of optical mineralogy, 3d ed. Part II.

Explanation of Plates

Fig. 1. Dolerite dike cutting gneiss. Grimstadnes, Ellingsøy.

» 2. *Sub-ophitic* texture of olivine dolerite. Reaction rim of garnet (black) between augite and plagioclase. + n. 50 ×.

» 3. Coarsegrained dolerite. Havnsund. Match-box 6 cm long.

» 4. Spheroidal structure on weathered surface of olivine dolerite. Vaksvik.

» 5. Idiomorphic olivine crystals in matrix of iron ores. Troctolitic dolerite. + n. 45 ×.

» 6. Part of a pseudoporphyric, optically anomalous orthopyroxene crystal. Blackened laths of plagioclase imbedded. Color of orthopyroxene mainly due to absorbtion, the uneven intensity of which is demonstrated. White fringe of the pseudoporphyric crystal is optically normal orthopyroxene of secondary origin (corona-pyroxene). + n. 45 ×.

» 7. Intergrowth of hypersthene (upper half) and augite (lower half). Two sets of cleavages cross the border line without any inclination. Pseudomorphs of garnet after plagioclase laths more or less enclosed in hypersthene. + n. 45 ×.

» 8. "Perthites" of orthopyroxene (in extinction position) in augite. + n. 45 ×.

» 9. Dolerite pegmatite in coarse-grained dolerite. Grimstadneset, Ellingsøy. To the left a shear-zone, parallel to the book.

» 10. Olivine-coronas. Upper crystal nearly replaced, lower, right crystal completely replaced. Garnet is black, orthopyroxene is fibrous, radiating. Lamination of plagioclase partly obliterated by secondary minerals. + n. 50 ×.

» 11. Grating pattern of micaceous crystals in plagioclase. The cross-cutting veins consist of (secondary) plagioclase and iron ore. Along the veins rims of garnet (black), branching into the plagioclase laths. + n. 45 ×.

» 12. Pseudomorphs after olivine. In the cores magnetite and some secondary orthopyroxene. The inner, white rim is orthopyroxene, the broad, composite, outer rim is garnet with border-zones of opaque matter. Plagioclase, mostly to the right, is crammed with tiny, secondary crystals. o. l. 45 ×.

» 13. Pseudomorphs of pyroxene after olivine, surrounded by garnet coronas with idiomorphic front towards plagioclase. Upper right corner: augite with amphibole-rim. Some idiomorphic garnet crystals in the inner part of plagioclase, also. Cf. fig. 3, p. 50. + n. 55 ×.

» 14. Amphibolitization of augite edges. Scattered garnets in plagioclase at some distance from augite. Cf. fig. 4, p. 51. + n. 50 ×.

» 15. Concentric alteration of hypersthene. Outer, black rim: garnet. Inner rim: diopside. Between the two, a third, less complete rim of biotite, replacing plagioclase, best seen in the upper left corner. In the biotite-"corona" also some secondary iron ore. Inside the diopside-corona there is a narrow zone in which the Schiller inclusions are resorbed. Cf. fig. 5, p. 52. + n. 45 ×.

Fig. 16. Left part: garnet-corona between plagioclase and augite (above) and hypersthene (below). Note the little rim of plagioclase left between the garnet-corona and the augite, the idiomorphic garnet crystals, especially towards plagioclase, and the greater width of the garnet-corona outside hypersthene. Right part: idiomorphic garnet and biotite in plagioclase. Cf. fig. 6, p. 53. o. l., 45 ×.

» 17. Transition stage between corona stage and granoblastic endstage of dolerite alteration. Large garnets are formed in the inner parts of plagioclase. Cf. fig. 8, p. 56. + n. 45 ×.

» 18. Symplectic intergrowth of diopside and plagioclase. o. l., 130 ×.

» 19. Interstitial biotite (light grey), probably pseudomorphs after iron ores, between idiomorphic olivine crystals. Note the tiny remnants of ore in the biotite surrounding the large ore crystals in the lower, right part. o. l., 45 ×.

» 20. Granoblastic texture of completely altered dolerite. White: plagioclase; ligt grey, small crystals: diopside; darker grey, larger sized, partly idiomorphic crystals: amphibole; light grey, highly refracting crystals: garnet (mainly upper, right side). Antiperthitic blebs in plagioclase can be seen some places. The scarce biotite crystals are difficult to distinguish from amphibole. Cf. fig. 9, p. 57. o. l., 45 ×.

» 21. Fine-grained dike in the dolerite at Haramsgrend, Haram. Between 0.5 and 1 m wide.

» 22. Granite pegmatite in dolerite, at Grimstadnes, Ellingsøy. White crystals: mostly albite, some quartz. Hammer handle 0.5 m long.

» 23. Same as in fig. 22, a few m apart.

» 24. Granite pegmatite close to the same locality as fig. 22. Only remnants of dolerite are seen. Width of pegmatite zone about 2 m.

» 25. Porphyric olivine and plagioclase in dolerite with *subdoleritic* texture. Uncertain locality. Serpentine has replaced olivine along fractures. o. l., 45 ×.

» 26. Clouded plagioclase. Lower left corner: iron ore with a narrow biotite corona and a wide garnet corona, partly adjacent to an idiomorphic olivine crystal. The black, interstitial crystal, partly adjacent to the same olivine, but mostly surrounded by clouded plagioclase, is augite. In the lower, right corner remnants of olivine with wide coronas of orthopyroxene and garnet. o. l., 45 ×.

» 27. Large crystal in central part is orthoclase. Note the gradual disappearance of the perthites. Upper part: biotite crystals in plagioclase. Between plagioclase and orthoclase a "corona" of recrystallized plagioclase. For more details see fig. 7, p. 54, which is a drawing of the same section. o. l., 70 ×.

» 28. "Opaque" augite interstitial towards (semi-opaque) laths of plagioclase and hypidiomorphic olivine. The olivine crystals completely imbedded in augite are smaller than the others. Note the wedge-form of the corona of the large olivine crystal.

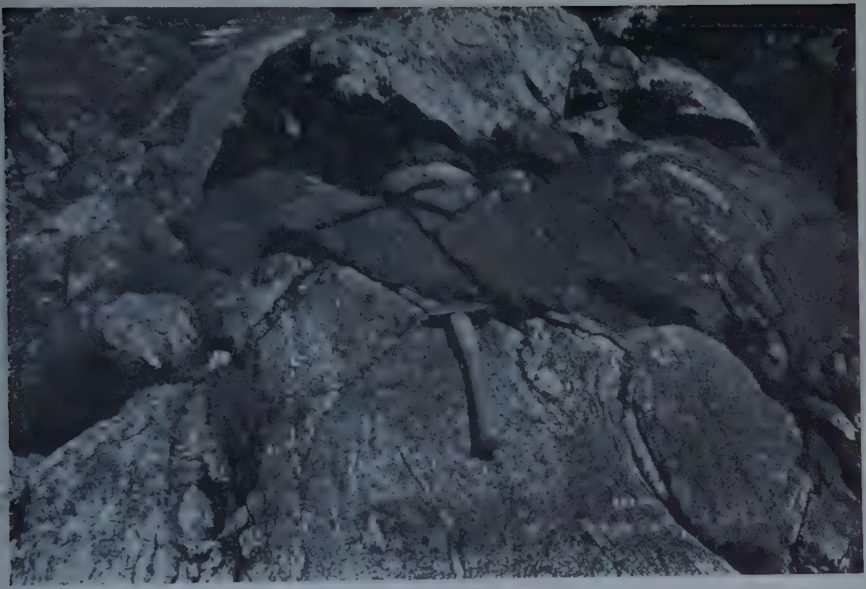


Fig. 1.

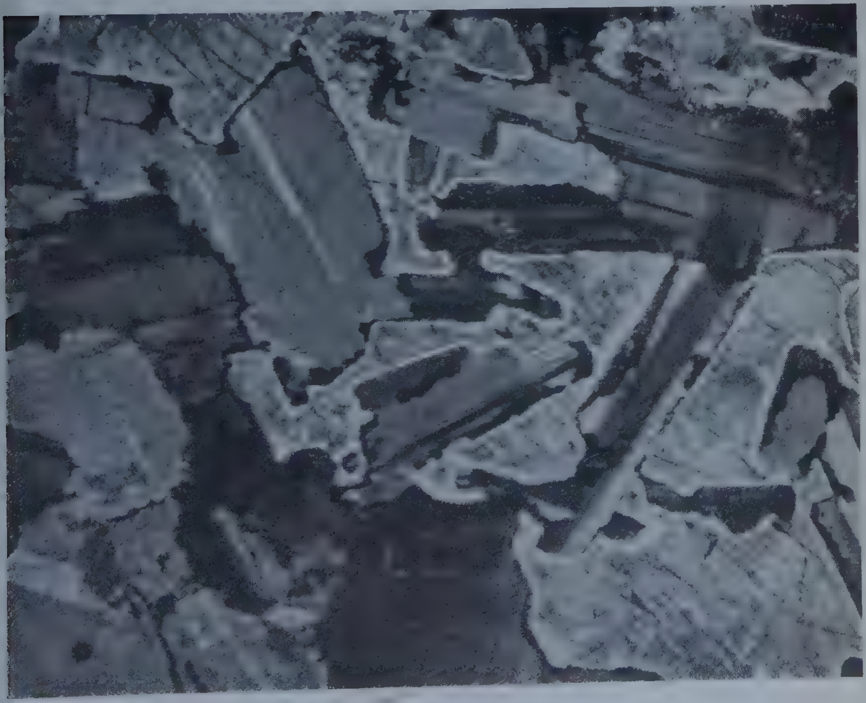


Fig. 2.

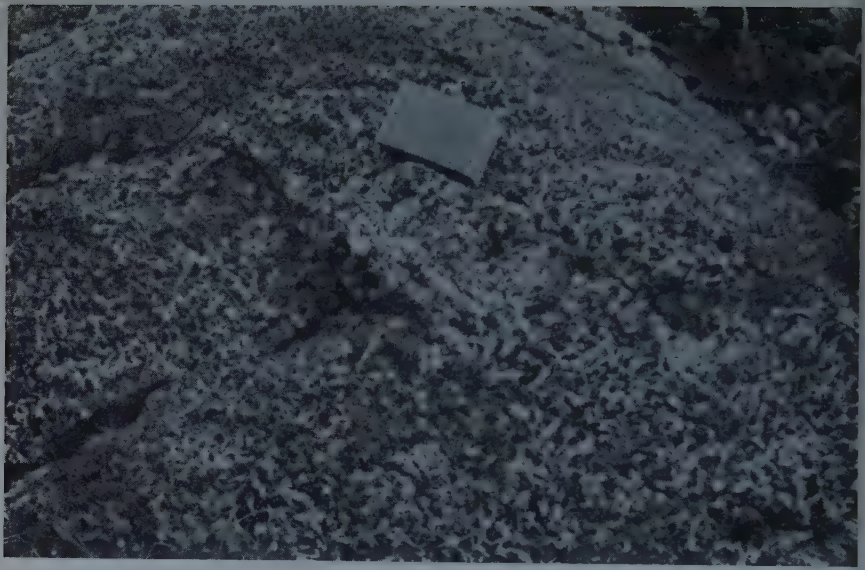


Fig. 3.

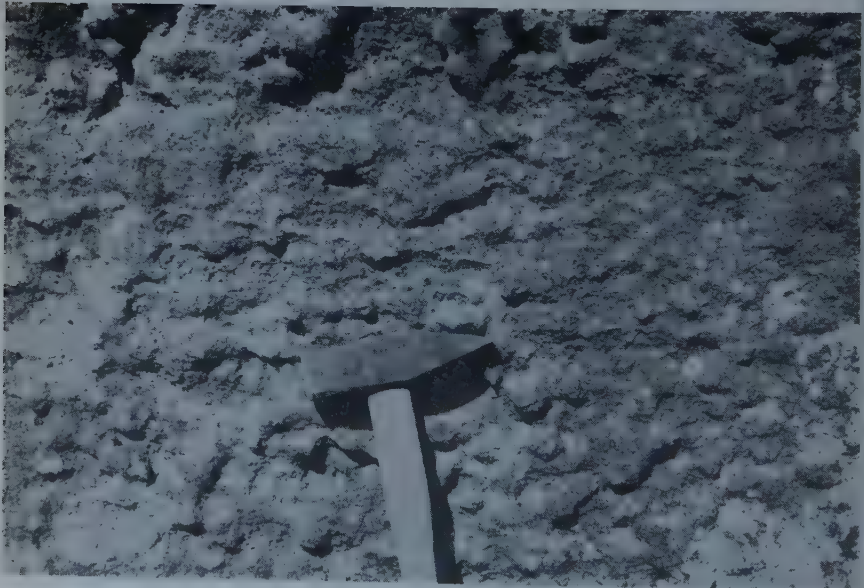


Fig. 4.

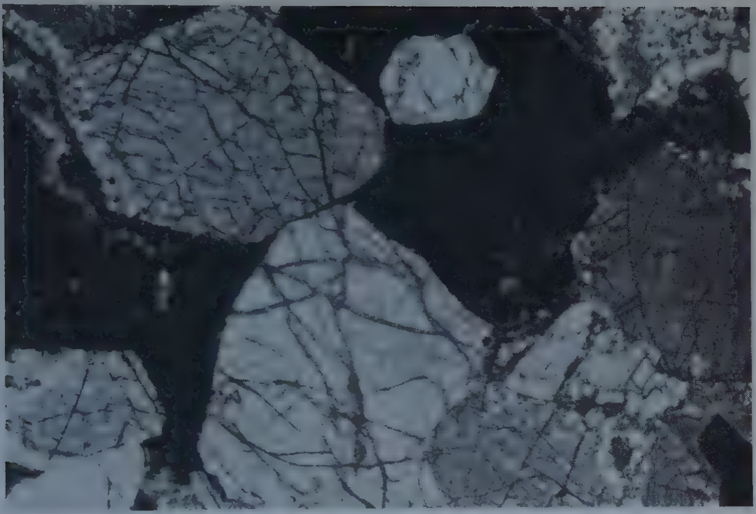


Fig. 5.

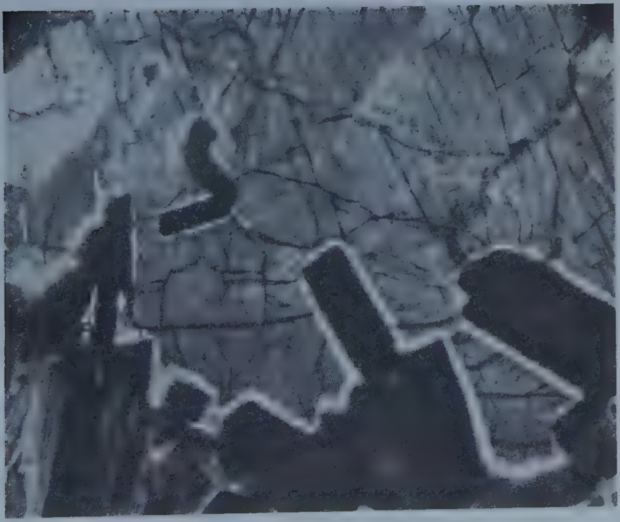


Fig. 6.

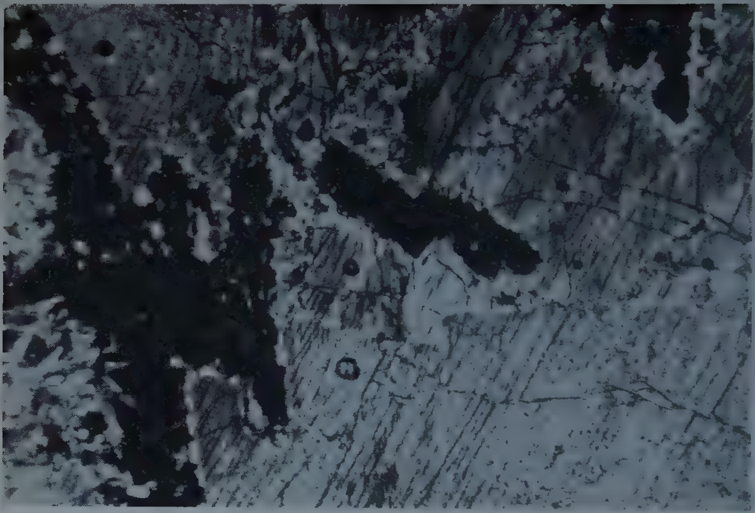


Fig. 7.

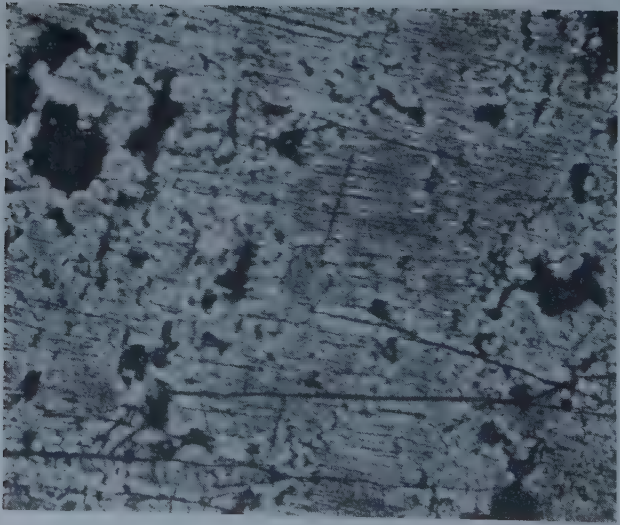


Fig. 8.

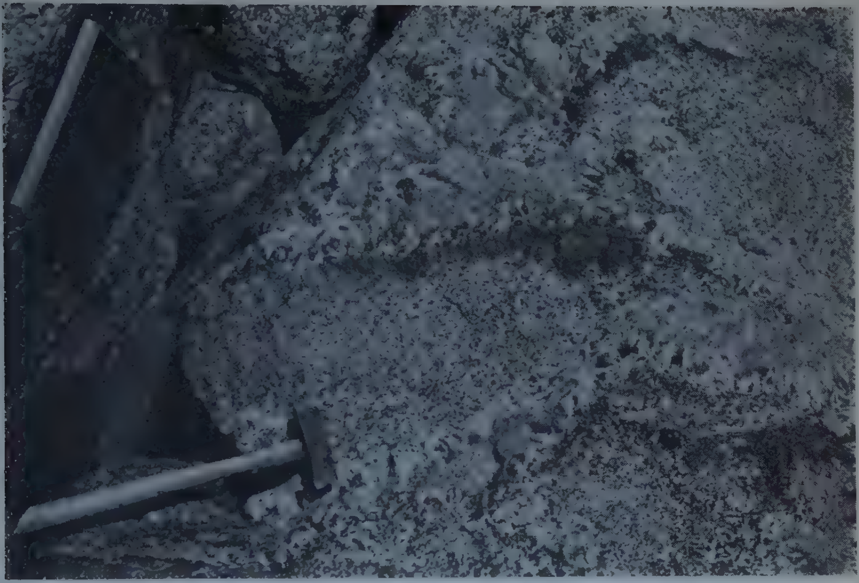


Fig. 9.

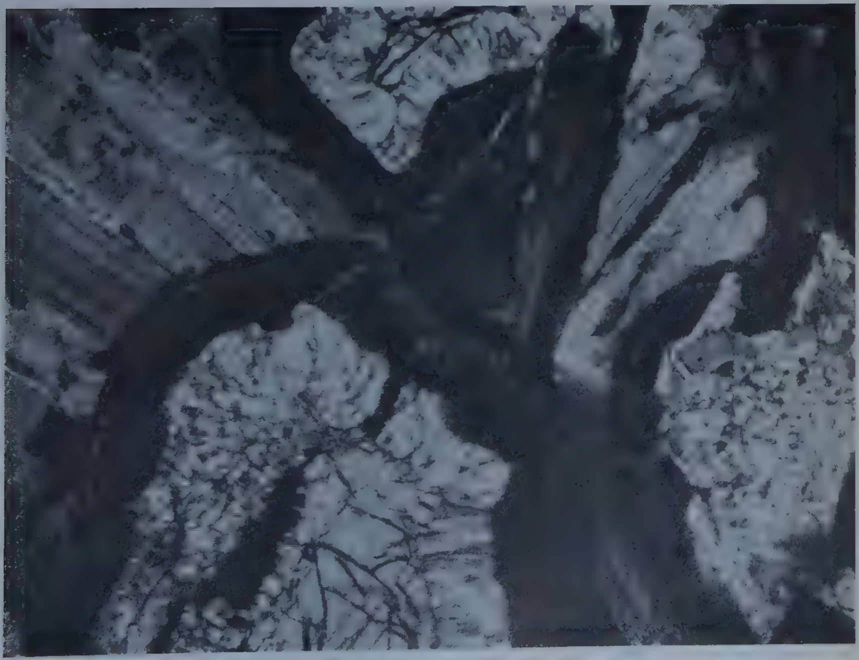


Fig. 10.

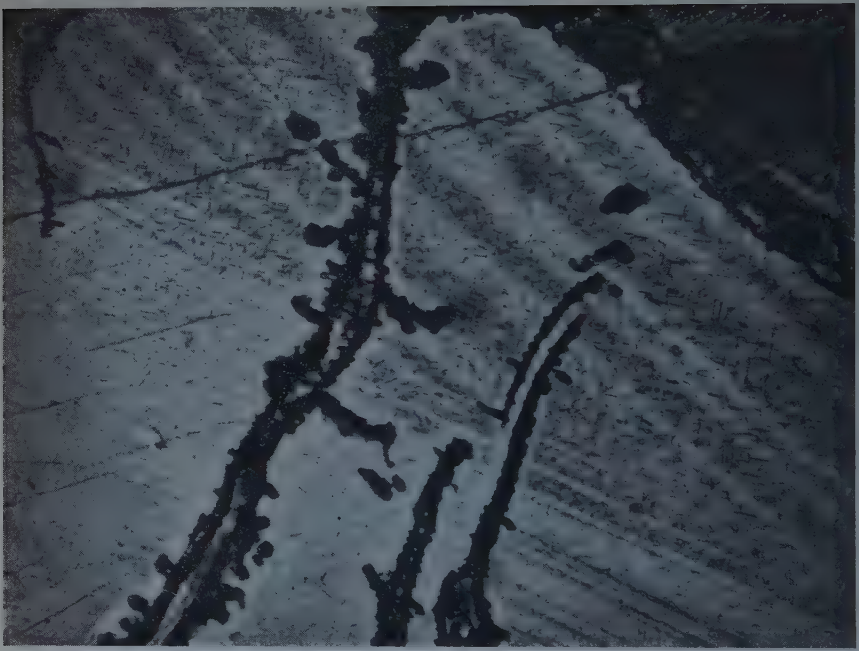


Fig. 11.

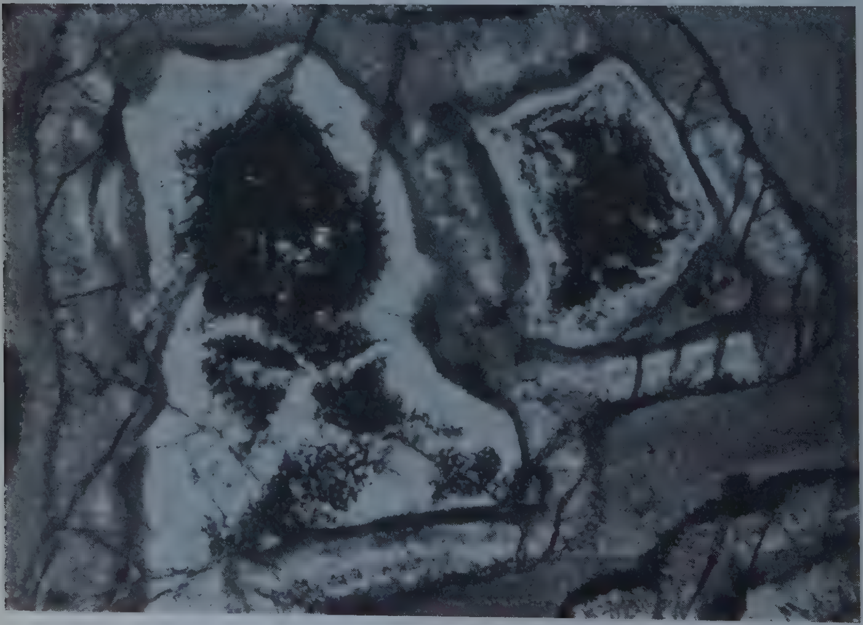


Fig. 12.

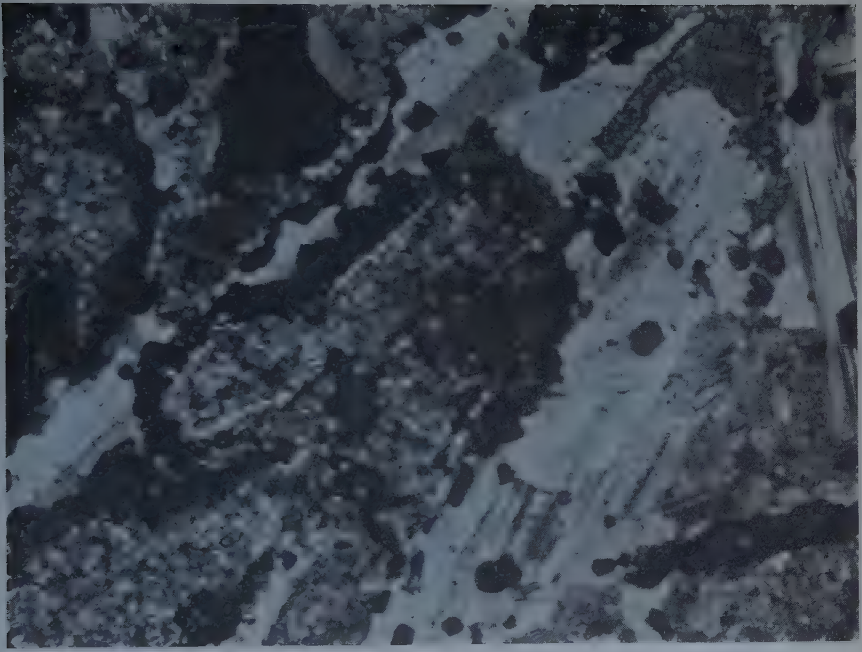


Fig. 13.

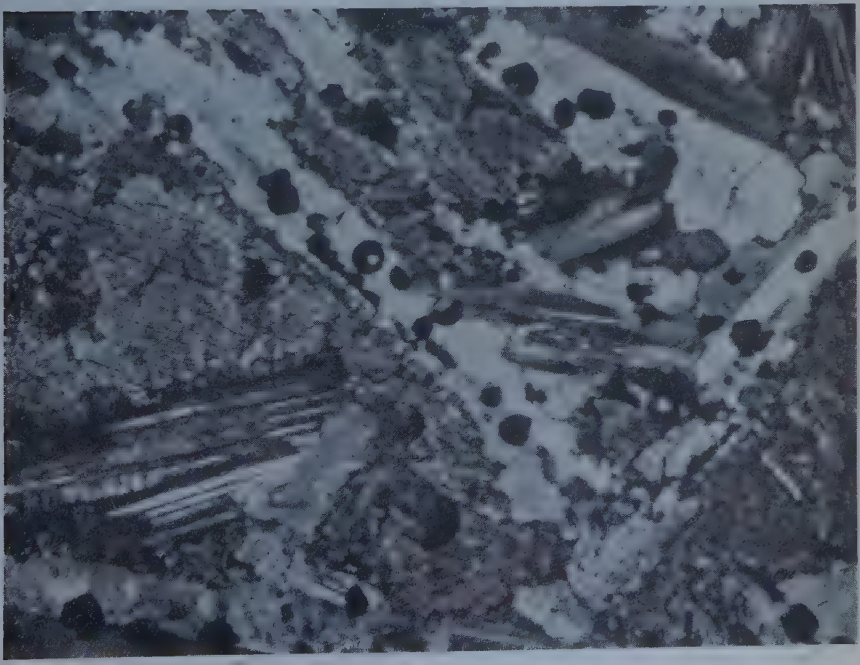


Fig. 14.

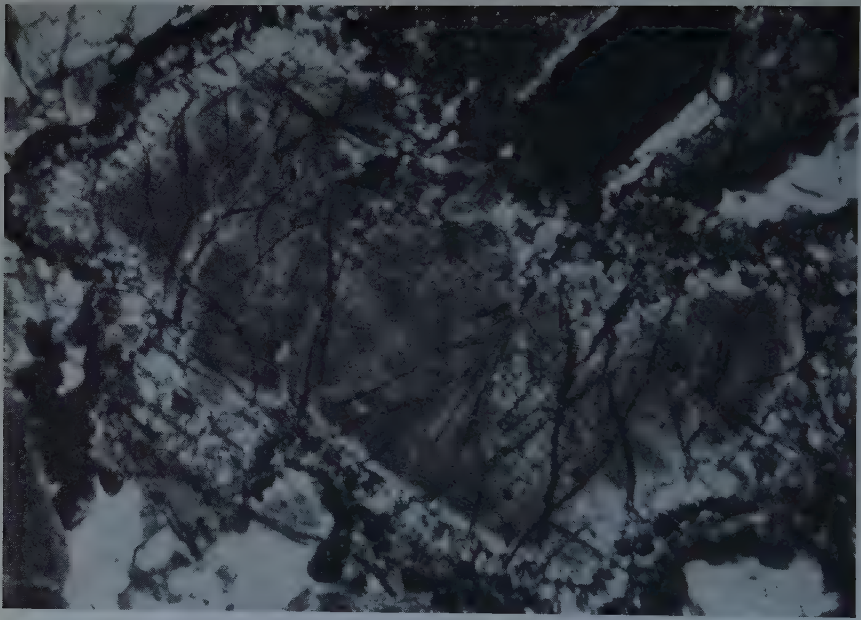


Fig. 15.

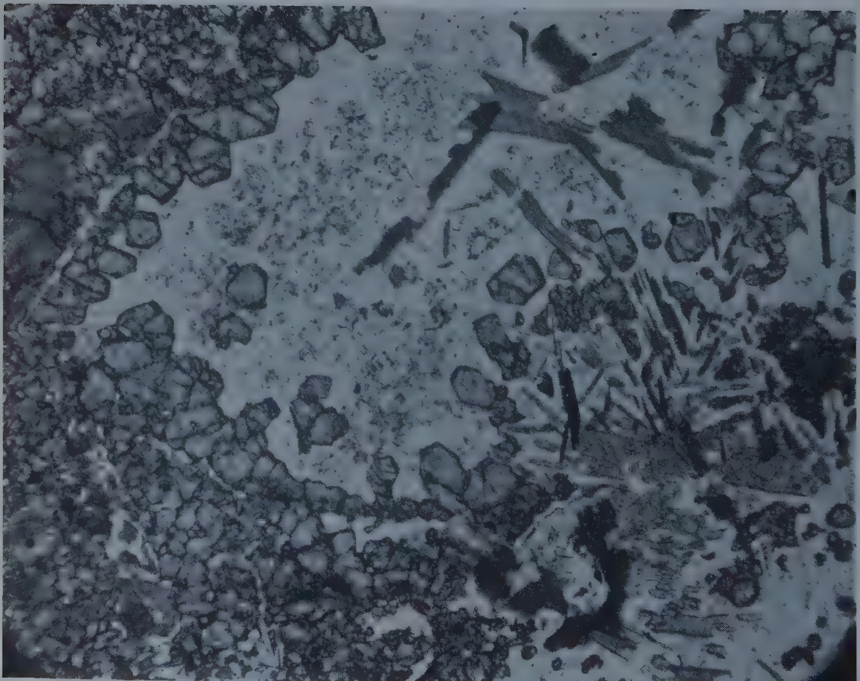


Fig. 16.

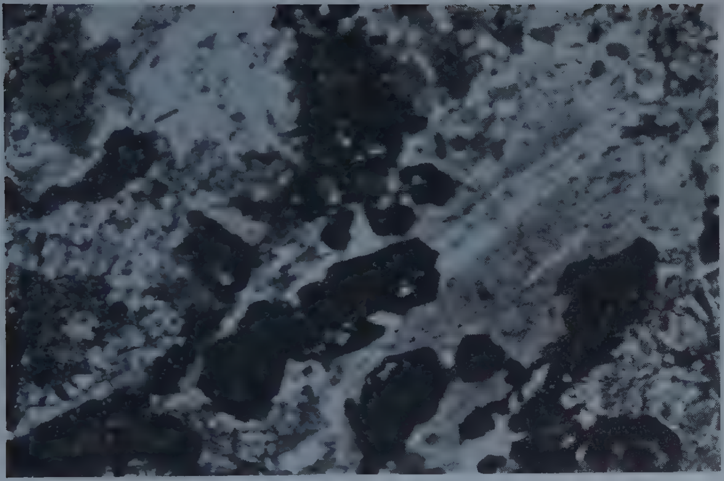


Fig. 17.

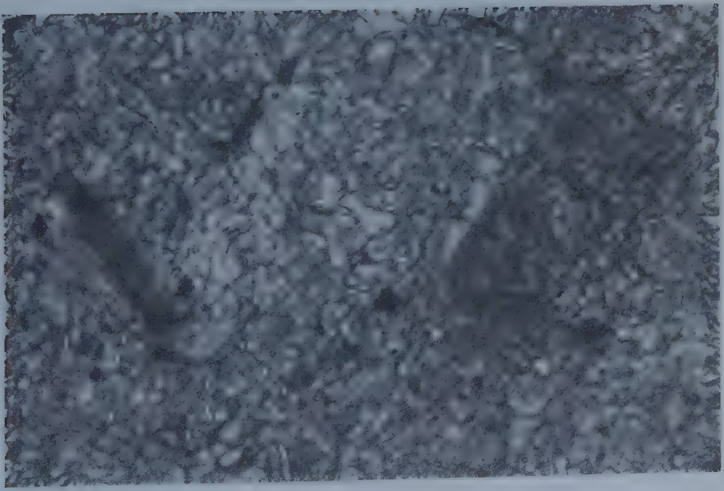


Fig. 18.

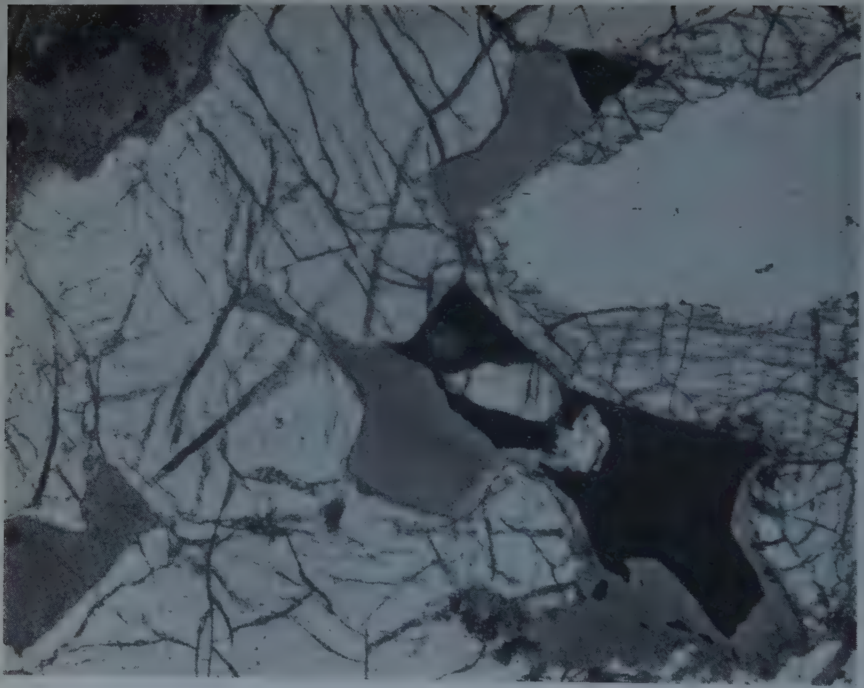


Fig. 19.

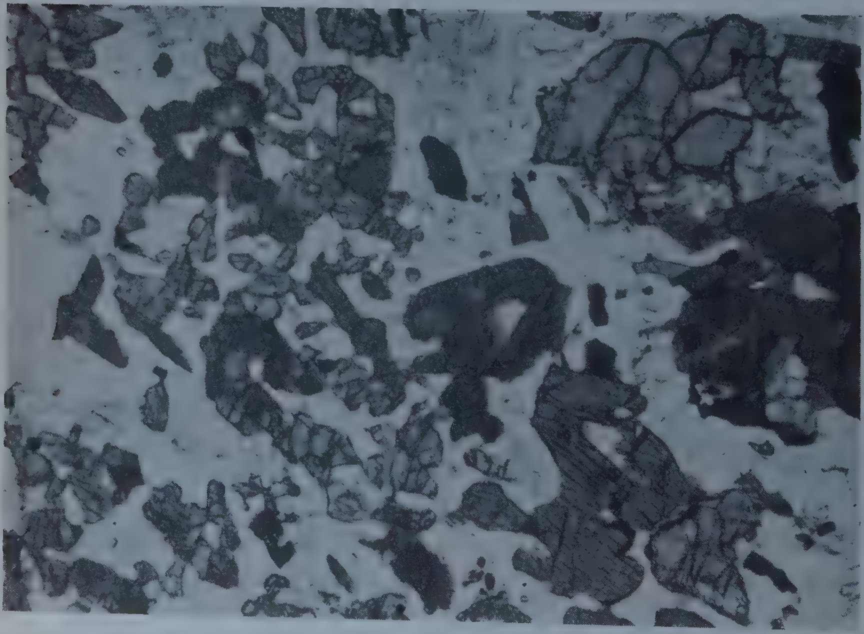


Fig. 20.

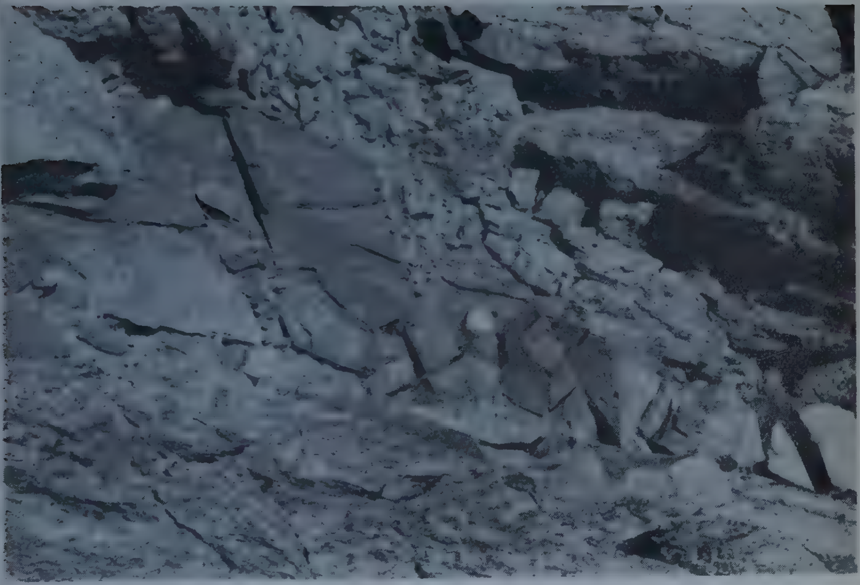


Fig. 21.

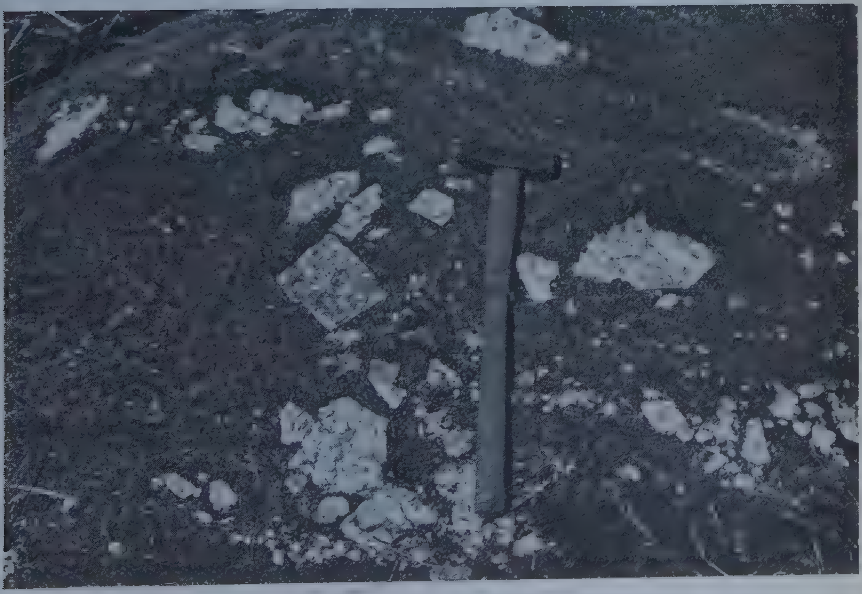


Fig. 22.

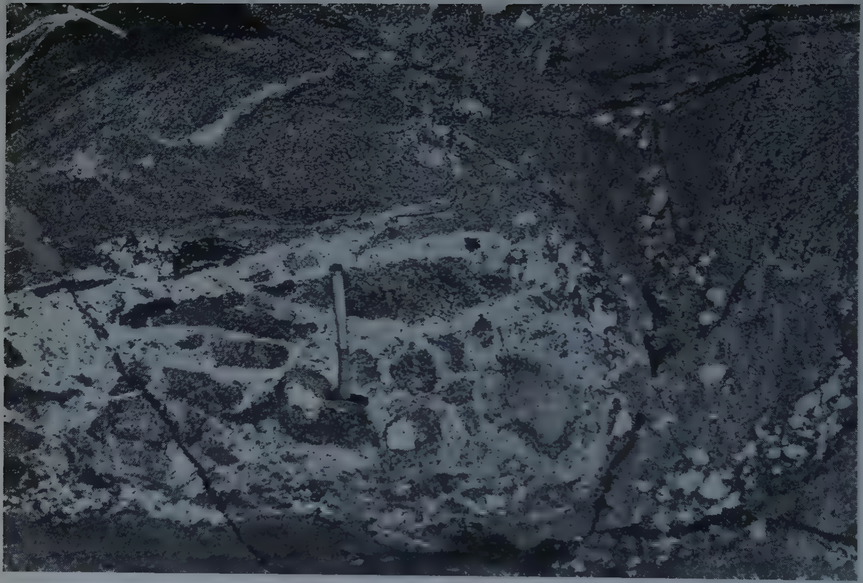


Fig. 23.

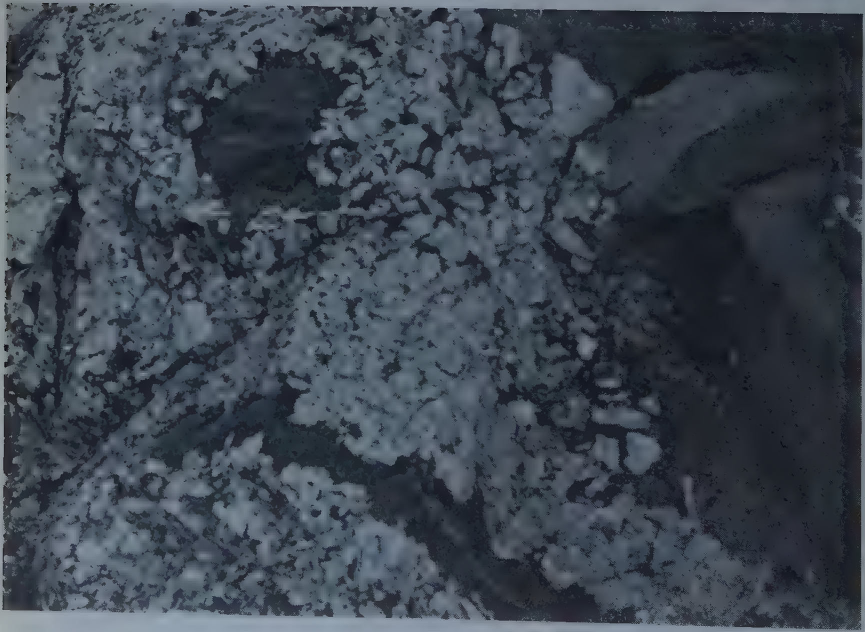


Fig. 24.

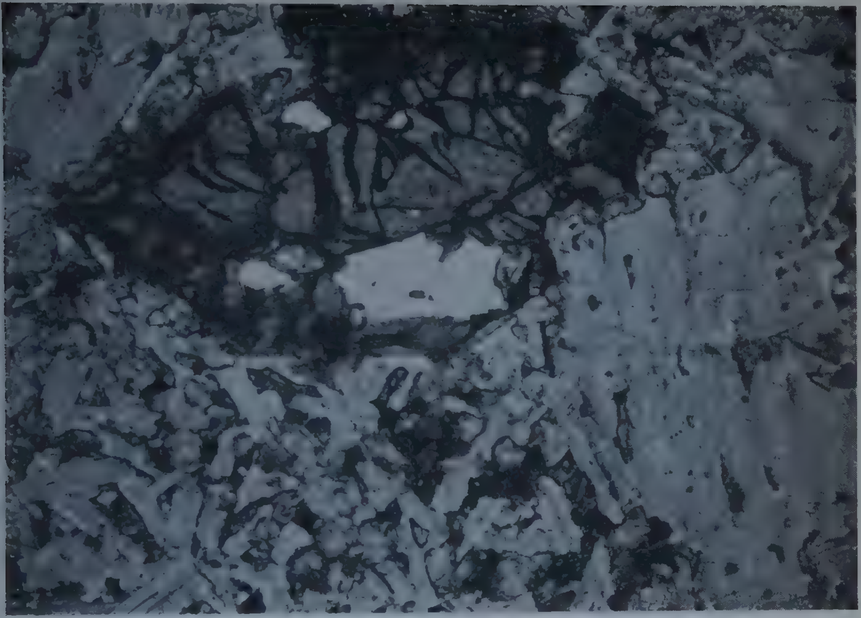


Fig. 25.

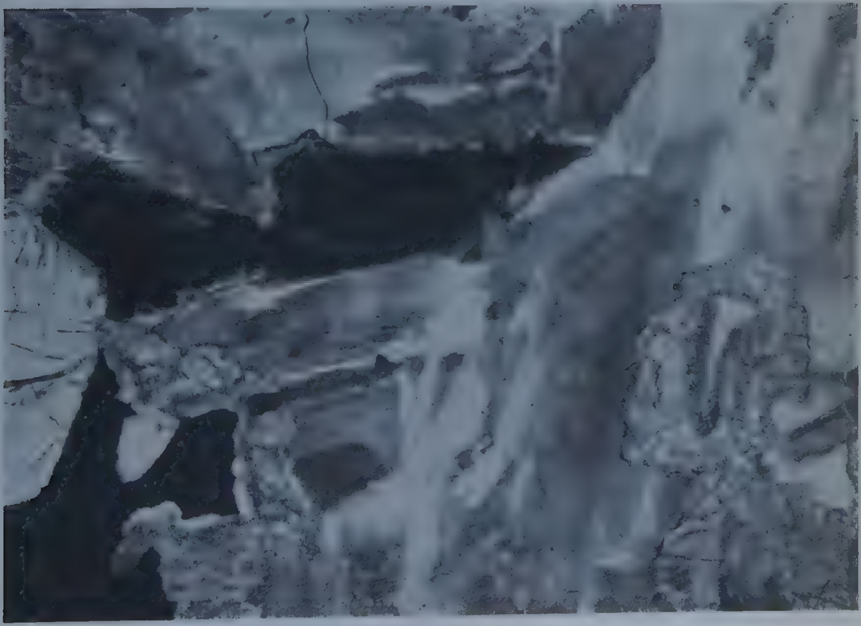


Fig. 26.

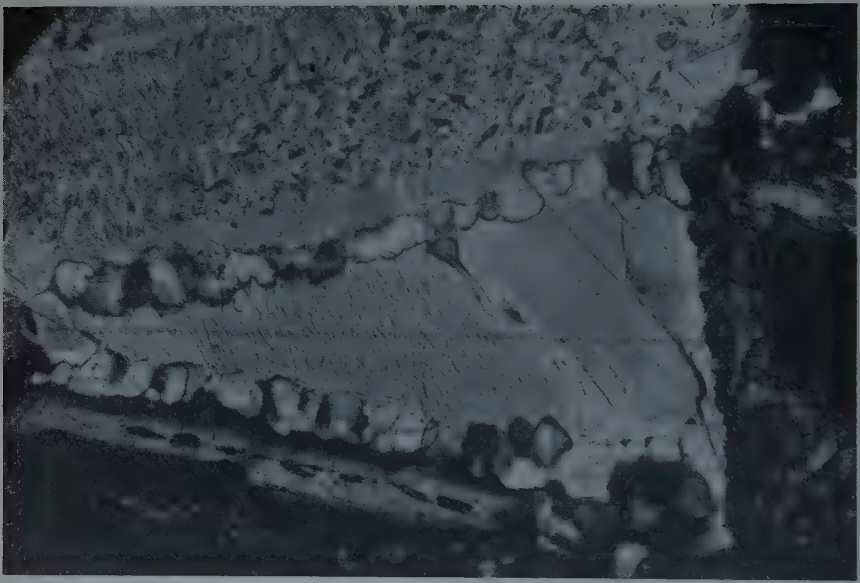


Fig. 27.

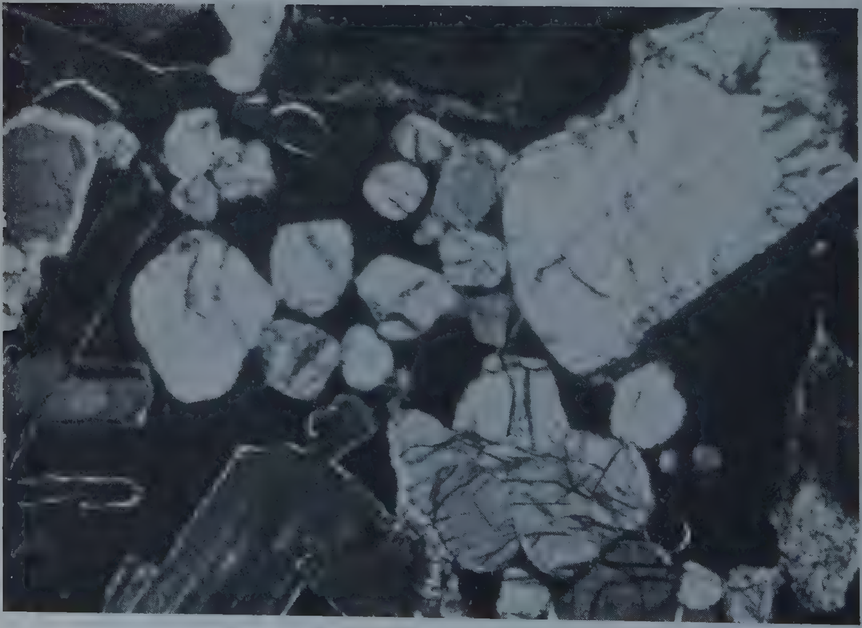


Fig. 28.

Tungsten in Southern Norway.

BY

OLGE J. ADAMSON AND HENRICH NEUMANN.

Recent work has proved a wide-spread tungsten mineralization in Southern Norway, where scheelite occurs in hydrothermal veins of precambrian age, and also in contactmetasomatic deposits and hydrothermal veins of permian age.

Previously scheelite was known in Fennoscandia in skarn rocks and granite pegmatites in Middle Sweden, in sulphide ores and as an accessory mineral in the rocks of the Ultevis complex in Northern Sweden, in sulphide ores in Southern and Southeastern Finland, and as a mineralogical rarity in certain rocks in the South and Southwest of Finland. In Norway scheelite was found in the Oslo Area by Professor V. M. Goldschmidt in the Skjerpemyr mine near Grua more than thirty years ago, and professor J. Schetelig identified it in a specimen from Sørumsåsen mine near the town Drammen ten years later.

Both places have been visited by the authors, and a quite extensive scheelite mineralization has been proved by the aid of a portable UV. lamp. In addition scheelite has been found in the following places: Lykkens Prøve mine west of Skjerpemyr near Grua (very scarce), Rørvik mine near Sørumsåsen, Oterdalen mine about 10 km S. E of the town Drammen, in a fault through the Narverud Iron mine about 6 km W. of Drammen, and in a specimen from Årvold about 8 km N. E. of Oslo.

At Grua and Årvold scheelite occurs in contactmetasomatic limestones. The paragenesis at Grua is calcite, quartz, andradite, monoclinic pyroxene, sphalerite, galena, chalcopyrite, pyrite, and scheelite. The hemimorphite, ilvaite, and uralite of Skjerpemyr are probably formed at a later stage.[1] At Sørumsåsen, Oterdalen and Rørvik near

---

[1] V. M. Goldschmidt: Die Kontaktmetamorphose im Kristianiagebiet. Videnskabsselskabets Skrifter I, no. 1. 1911.

Drammen scheelite is found in quartz veins together with molybdenite. The deposits have been worked as molybdenum mines but the tungsten content was never detected and went to waste.

A systematic survey of hydrothermal veins and metasomatically altered limestones in the Oslo Area would probably give a number of additional finds.

The above-mentioned deposits were formed by hydrothermal solutions originating from the plutonites of the Oslo area, which were intruded in the "Vorland" of the variscian mountain chain. As the majority of the tungsten deposits in Europe are found in the variscides a tungsten mineralization in the Oslo area is not so surprising.

In the border zone of the precambrian Ekersund formation towards the Telemark formation wolframite was found in the Ørsdalen molybdenum mines about 1910, and about 10 years later an appreciable content of scheelite was recognized in the ores of this area. One of the Ørsdalen deposits was worked as a tungsten mine from 1937 till the end of the war, and is now reopened.

In September 1950 the authors, accompanied by Professor Tom. F. W. Barth, made a rapid survey of several hydrothermal deposits of the Telemark formation and new finds of scheelite were made in the following places: Dalen and Askom molybdenum mines near the western end of the lake Bandak, Tarjeisberg molybdenum deposit west of Nisservann, and in Bleka gold-mine in Svartdal (scarce). The Dalen, Askom and Tarjeisberg deposits are all formed by hydrothermal solutions exuded from the precambrian Telemark granite. That may be true of the hydrothermal goldbismuth veins at Bleka also, but their genesis should not be discussed in this paper.

An abnormally high tungsten content has been established in the precambrian areas west of the Oslo Fiord, while the pegmatites in Østfold (east of the Oslo Fiord) contain little or no tungsten.[2], [3], [4]. A columbite from Tveit, Iveland contains as much as 13.00 % WO_3.[2]

---

[2] Harald Bjørlykke: The mineral paragenesis and classification of the granite pegmatites of Iveland, Setesdal, Southern Norway. Norsk Geologisk Tidsskrift XVII, pp. 1—16. (1937).

[3] Harald Bjørlykke: Mineral parageneses of some granite pegmatites near Kragerø, Southern Norway. Norsk Geologisk Tidsskrift XVII, pp. 1—16. (1937).

[4] O. J. Adamson: The granite pegmatites of Hitterø, Southwestern Norway. Geologiska Föreningens i Stockholm Förhandlingar LXIV, pp. 97—116. (1942).

In the western precambrian area in Southern Norway three precambrian formations have been recognized: The Kongsberg—Bamble formation, the Telemark formation, and the Ekersund formation. The two first-mentioned ones are probably genetically identical and are formed contemporaneously at different depths.[5]

As to the age of the Ekersund formation which consists of anorthosites and charnockitic rocks, no definite statement can be made. In the opinion of the authors it may well be older than the other two, and the tungsten-bearing pegmatites on the island of Hitterøy and the hydrothermal veins of Ørsdalen, both in the Ekersund formation, may originate from younger igneous rocks of the Telemark and Kongsber—Bamble formations.

Our present knowledge can be summarized as follows: In the precambrian a tungsten mineralization has taken place in connection with the Kongsberg—Bamble—Telemark orogeny, while tungsten is a non-characteristic element in the East-Norwegian precambrian area, and probably also in the Ekersund formation.

In Caledonian rocks and ore deposits tungsten has not been looked for, a survey of the pyrite deposits would be worth while in view of the recent finds of scheelite in several sulphide ores in Northern Sweden.[6]

In the variscian Oslo area a wide spread tungsten mineralization has been established.

A grant from Norges Teknisk Naturvitenskapelige Forskningsråd is gratefully acknowledged. We also want to thank Mr. A. Kvalheim of Statens Råstofflaboratorium, who has checked spectrographically our identifications of scheelite.

Geologisk Museum,
Oslo 45.
January, 1952.

---

[5] Tom. F. W. Barth: The large pre-cambrian intrusive bodies in the southern part of Norway. Report of XV International Geological Congress Washington, 1933.

[6] E. Grip: Tungsten and molybdenum in sulphide ores in Northern Sweden. Geologiska Föreningens i Stockholm Förhandlingar. LXXIII, pp. 455—472, (1951).

ON THE LOWER DIDYMOGRAPTUS ZONE (3 B) AT RINGSAKER, AND CONTEMPORANEOUS DEPOSITS IN SCANDINAVIA

BY

STEINAR SKJESETH

Contents.

Abstract 138
Acknowledgement 139
Introduction 139
Historical account of earlier research 139
An introduction to the stratigraphy and tectonics of Southern Ringsaker 140
The Lower Didymograptus Zone (3 b) at Ringsaker 143
Notes on the sediments 147
Correlation of the 3 b sediments in Scandinavia 148
The Planilimbata Limestone, "The Planilimbata Zone" 155
Systematic description of trilobites 156
  Family Agnostidae 157
    — Remopleurdiidae 157
    — Asaphidae 158
    — Styginidae 171
    — Cheiruridae 173
    — Lichadidae 174
    — Ceratopygidae 175
    Raphiophoridae 176
References 179
Expanation of plates 173

Abstract. The two upper sub-zones of the Lower Didymograptus Beds (3 b) appear in limestone-trilobite facies at Heramb, Ringsaker, Norway. The layers at Heramb correspond to the Planilimbata Limestone, or part of it, and the beds are correlated with corresponding deposits elsewhere in Scandinavia. The 3 b sediments are deposited in a more or less closed basin on the Scandinavian Foreland. In this basin the different facies of the 3 b sediments have a distinct distribution. The trilobites from the upper subzones of 3 b at Heramb are described, among them three new trilobite species:

Megalaspis ringsakerensis sp. n.
Ptychopyge herambensis sp. n.
— *minor* sp. n.

Ampyx volborthi Schmidt is transferred to the genus *Lonchodomas*.

ACKNOWLEDGEMENT

It is a pleasure to express my heartiest and most sincere thanks to Professor L. Størmer and Curator G. Henningsmoen for their valuable advice and friendly help during my studies and the preparation of this paper. I also wish to express my sincere thanks to Professor A. Heintz for offering me the best of facilities for my research at the Paleontological Museum. Through the courtesy of Professor E. Stensiö, I have had the advantage of borrowing material from the Riksmuseet, Stockholm.

Introduction.

While mapping geologically the Nes peninsula in Mjøsa in the central part of the southern Norway in the summer 1948, I became aware of a rather good section through the upper part of the Lower Didymograptus Zone (= Phyllograptus Zone, 3b) at the locality Heramb in the southern part of the parish of Ringsaker. The zone 3b and the boundary between this and the above-lying Orthoceras Limestone (3c) is well exposed. The transition from black graptolite shale to limestone is continuous or, at least, without visible breaks.

The locality Heramb was visited several times during the summers 1948—50, and a rich collection of fossils was brought to the Paleontological Museum, Tøyen, Oslo for examination.

At least the two upper subzones of 3b at Heramb have developed as a grey mudstone with interbedded limestone lenses containing a rich trilobite fauna which will be described below in a special chapter. Besides trilobites, well preserved graptolites and ostracods occur in the limestone lenses and the mudstone. At least the two upper subzones of the Lower Didymograptus Zone viz. 3bγ—3bδ (cf. Monsen 1937, p. 72) have a different facies from that of the same sub-zones in the vicinity of Oslo. The trilobites suggest that these sub-zones at Heramb correspond with the Planilimbata Zone in Sweden.

Historical account of earlier research.

The stratigraphy of Ringsaker is quite well known thanks to a series of detailed stratigraphical works. The Eocambrian (Sparagmitian)—Cambrian transition was treated by Vogt 1925, the Lower Cambrian by Kiær 1916, the Cambrian and the Lower Ordovician by Strand 1929 and the Middle Ordovician by Holtedahl 1909. These papers contain references to other geological works from the parish. Only a few remarks, however, have been given on the Lower Didymograptus Zone (3b).

Brøgger (1882, p. 20) mentions Phyllograptus angustifolius from Ringsaker. In his paper of 1929 (pp. 326—27), Strand also has a note on the Lower Ordovician of the Mjøsa District in which he i. a. states that "The shales of 3b fall in two divisions, a lower consisting of a green or grey shale with lenses of limestone and an upper black graptolite shale with Didymograptus, Tetragraptus and Phyllograptus forms. At Stensodden, Ringsaker, a greeninsh grey shale with limestone-lenses, belonging to the lower division, has been found with the following fauna: Lingulella lepis, Eoorthis christianiae, Ceratopyge forficula, Niobe insigns, Megalaspis stenorachis?."

An introduction to the stratigraphy and tectonics of Southern Ringsaker.

The stratigraphical sequence of S. Ringsaker is as follows:

7 a—b.	Pentamerus Limestone.
6.	Quartzite.
....	
	Hiathus.
....	
4 b.	Mjøsa Limestone.
4 b.	Cyclocrinus beds.
4 b.	Coelosphæridium and Mastopora beds.
4 a—4 b.	Robergia Beds.
4 a α.	Ogygiocaris Shale.
3 c.	Orthoceras Limestone.
3 b.	Lower Didymograptus Zone (Planilimbata beds).
3 a.	Ceratopyge beds.
2 e.	Dictyonema Shale.
2 a—2 d.	Upper Cambrian.
1 c—1 d.	Middle »
1 a—1 b.	Lower »
Eocambrian (= Sparagmitian)	Ringsaker Quartzite. Vardal Sparagmite.

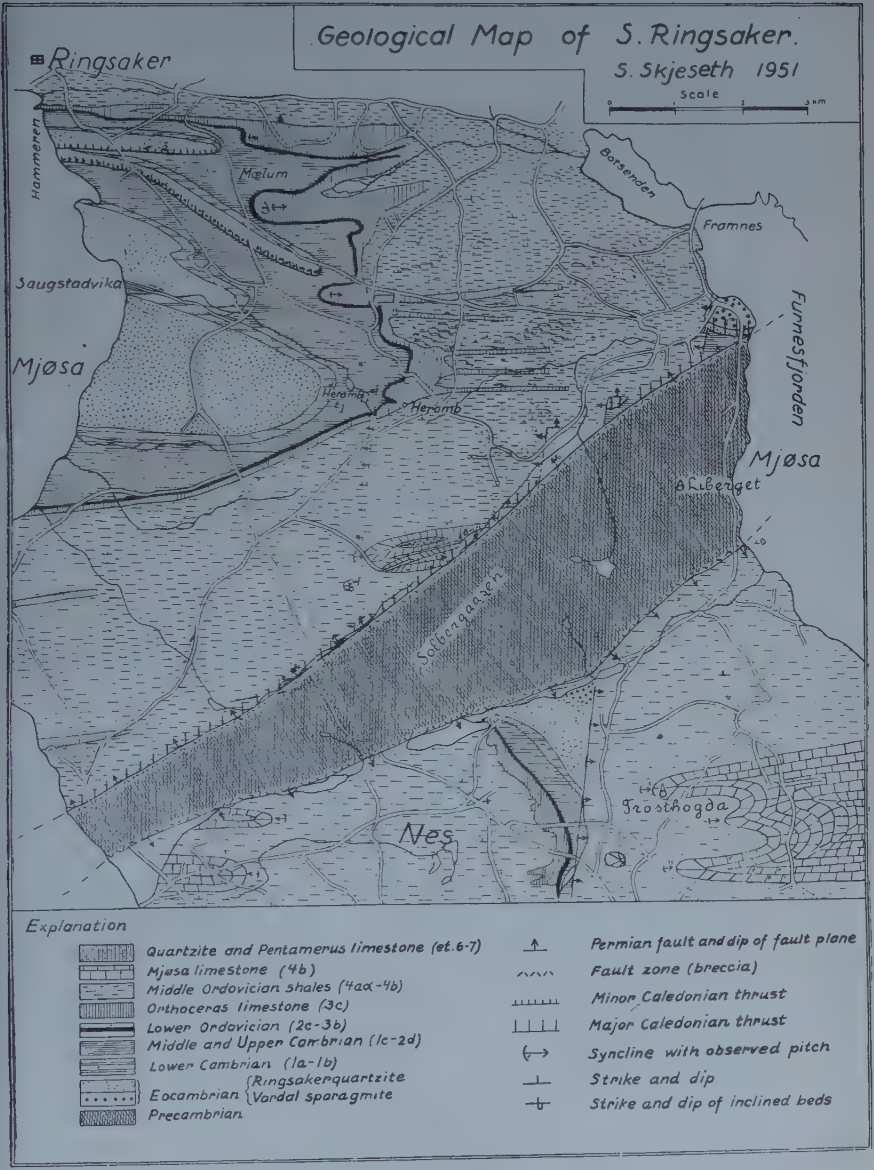

Geological Map of S. Ringsaker.
S. Skjeseth 1951
Scale
Ringsaker
Hammeren
Mælum
Botsenden
Framnes
Saugstadvika
Mjøsa
Furnesfjorden
Heramb
Mjøsa
Liberget
Solbergaasen
Trosthogda
Nes
Explanation
Quartzite and Pentamerus limestone (et.6-7)
Mjøsa limestone (4b)
Middle Ordovician shales (4aα-4b)
Orthoceras limestone (3c)
Lower Ordovician (2c-3b)
Middle and Upper Cambrian (1c-2d)
Lower Cambrian (1a-1b)
Eocambrian {Ringsakerquartzite / Vardal sparagmite
Precambrian
Permian fault and dip of fault plane
Fault zone (breccia)
Minor Caledonian thrust
Major Caledonian thrust
Syncline with observed pitch
Strike and dip
Strike and dip of inclined beds

Fig. 1. Geological map of Southern Ringsaker.

As shown on the geological map (fig. 1) the Sparagmitian, Cambrian and the Lower Ordovician are distributed on the Western side of the peninsula in Ringsaker, whereas the Middle Ordovician has its main distribution on the eastern side.

The only marked break in the sedimentation occurs above the Mjøsa Limestone. This limestone of Middle Ordovician age (Størmer 1945, p. 393), is overlain by a silurian quartzite most probably corresponding to the Phacops quartzite in Sweden (cf. Thorslund, 1943). The rock complex in Southern Ringsaker forms an anticlinorium. This is well marked in the terrain. Synclines of the Orthoceras Limestone project out as wooded heights, whereas the anticlines are eroded. The axis of the folds pitch constantly 15—20 degrees to the east. This pitching is due to Permian faulting, causing an increasing subsidence towards a north-south main fault zone in the east, viz. the Brumund Valley fault zone.

The boundary between Ringsaker and the neighbour parish of Nes is marked by a rather narrow Permian horst. The rocks in the horst mainly consist of coarse Precambrian granites and augengneisses. On the northern side of the horst there are some small areas of quartzite, sparagmite and Cambrian alum shale, which are limited by minor faults coming from the main fault zone. Within these areas the Eocambrian sparagmite and quartzite are thrusted over alum shales.

The rocks in the district are folded and thrusted by Caledonian movements. Several minor overthrusts occur. The competent quartz-sandstones have developed a typical imbricate structure partly affecting the overlying Cambro-Silurian shales and limestones. The alum shales have developed minor drag folds while the competent Ordovician limestones viz. The Orthoceras- and the Mjøsa limestones form bigger folds. The folding plains as well as minor thrusts mainly dip at high angles towards the north-west. The two northern quartz-sandstone areas (see the map) are thrusted over Cambrian layers. These thrusts must also be of small dimensions since the change into typical thrustfolds in the Cambro-Ordovician layers above. The geology of the Mjøsa district suggests that the Cambro-Silurian of Southern Ringsaker belongs to an allochthonous complex with its front passing through Høsbjør, Gjøvik and northern Randsfjord (see Holtedahl 1934, p. 339). The above-mentioned Eocambrian-Cambrian areas on the northern side of the horst may represent small sections of the main thrust near the thrust plane. The main thrust is a low angle thrust dipping about 15 degrees to the north-west. In my opinion, the quartzites belong to the allochthonous, whereas the Cambrian alum are a continuation northwards of the parauthocthonous Cambrian shales south of the horst. The Cambro-Silurian in Southern Ringsaker must, according to this, have subsided considerably and now forms a graben limited by Permian fault zones in the west, south and east. We thus have a parallel to the Oslofjord graben here at the northern corner of the Oslo Region.

The Lower Didymograptus Zone (Phyllograptus Zone, 3 b) at Ringsaker.

In Southern Ringsaker the Lower Didymograptus Zone corps out at several places along the inner edge of the anticlinorum which is so well marked by the Orthoceras Limestone. The incompetent shale as well as the Middle and Upper Cambrian alum shales are squeezed. out. The conditions are thus rather complicated. On the geological map (p. 141) the Lower Ordovician (Dictyonema Shale, Ceratopyge Beds and the Lower Didymograptus .Zone) is marked out with black colour. The thickness of these layers is exaggerated on the map. The above-mentioned zones are drawn nearly continuously within the anticlinorum; this is, however, slightly misleading as the shale often is covered by moraine and scree material mainly from the Orthoceras Limestone above. Where the thickness is measured it varies considerably, largely due to tectonic compression of the shale. Usually the stratigraphy is difficult to make out in detaile, but in one locality this has been possible.

At the northern slope of an east-west dell (an eroded anticline) which begins just north of the houses of the farm Heramb and runs down to Herambstjernet (the Heramb lakelet) two cuttings through the Lower Didymograptus Zone occur. The shales here are used as road gravel, and in two gravel pits the Lower Didymograptus Zone and the transitional layers from this to the Orthoceras Limestone are well exposed. The 3b shale lies as a kernel in an inverted anticline of Orthoceras Limestone. The layers just below the limestone on the northern limb of the fold lie relatively undisturbed, whereas the shales in the central and inverted part of the anticline are disturbed by folding and minor thrusts. In the gravel pits the contact between 3b and the Orthoceras Limestone, as well as about 2.5 meters of 3b are exposed.

The exposed section begins from below with a black graptolite shale (black streak) with big pyrite concretions. Then follows a typical speckled shale and next a grey streaked shale. In these shales forming the lower 0.30 m of the section, the following graptolites were found:

Phyllograptus densus Törnquist.
Tetragraptus quadribranchiatus (J. Hall).
Didymograptus balticus Tullberg.
—»— sp.
Trichograptus sp.

These shales thus correspond with the sub-zone of *Didymograptus balticus* and *Phyllograptus densus,* sub-zone 3 b β in the vicinity of Oslo. From 1.50 m below the Orthoceras Limestone and upwards follows a grey argillaceous limestone with limestone lenses. In the lower part the lenses are large and occur scattered in the mudstone and contain pseudomorphoses of gypsum crystals. Approaching the Orthoceras Limestone the lenses decrease in size, lie more close together and are arranged in continuous bands. Close to the limestone boundary a thin nodular limestone bench occurs. The mudstone and especially the limestone lenses are rich in fossils. The fauna is a mixed fauna with graptolites, trilobites, brachiopods and ostracoda. Uncompressed graptolites occur together with trilobites in the same limestone lense. The following graptolites are found in the mudstone and the interbedded limestone lenses:

Dichograptus octobranchiatus (J. Hall).
Tetragraptus serra (Brongniart).
—»— *bigsbyi* (J. Hall).
Didymograptus cf. *grandis* Monsen.
—»— *extensiform.*
Phyllograptus angustifolius J. Hall.
—»— —»— *elongatus* Bulman.

The graptolite assemblage suggests that the grey mudstone corresponds with the two upper subzones of the Lower Didymograptus

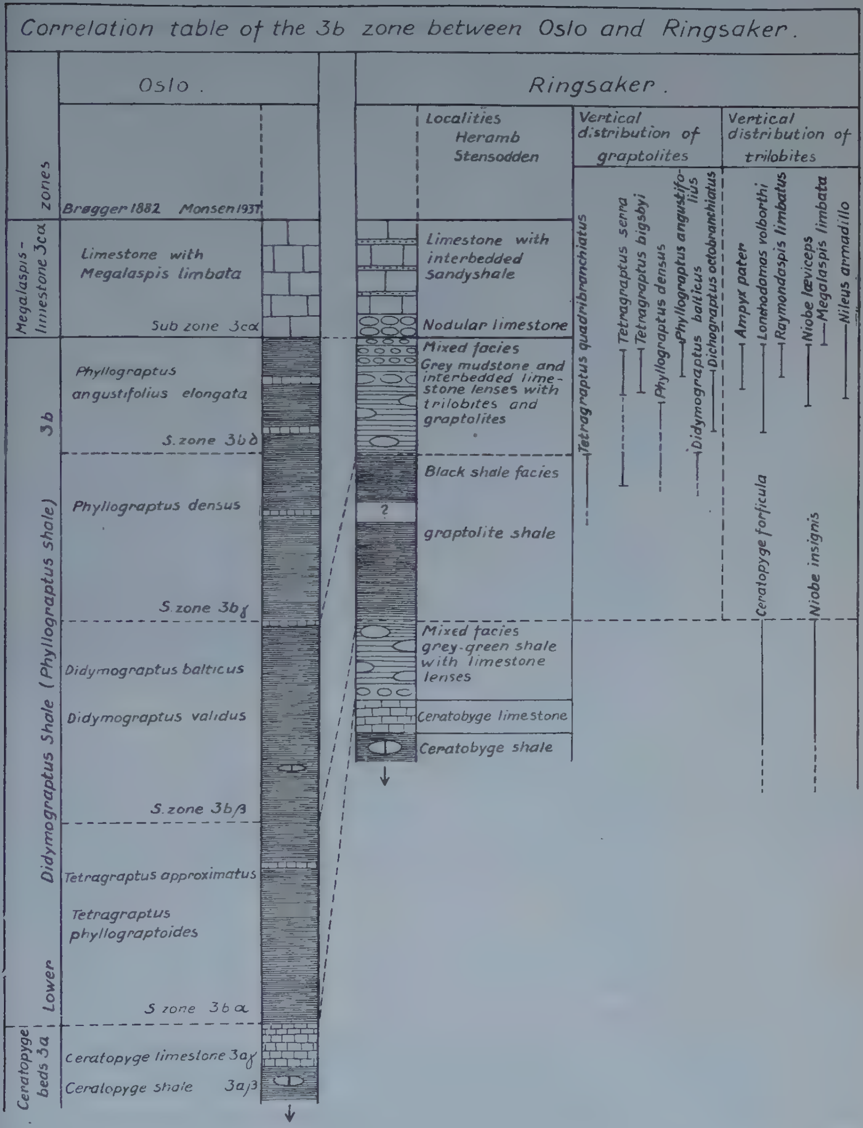


Fig. 2. A correlation of the Oslo and the Ringsaker developments of 3 b.

Shale near Oslo. It is impossible to separate these subzones either by means of the fossils or the lithology. In addition to the graptolites the folowing fauna is found mainly in the limestone lenses:

Trinodus glabratus (Angelin).
—»— sp.
Ampyx pater Holm.
Lonchodomas volborthi (Schmidt).
Remopleurides aff. *nanus* (V. Leuct.).
Megalaspis ringsakerensis sp. n.
—»— *polyphemus* Brøgger.
—»— *planilimbata* Angelin.
Ptychopyge herambensis sp. n.
—»— *minor* sp. n.
Niobe læviceps (Dalman).
Nileus armadillo (Dalman).
—»— *limbatus* Brøgger.
Symphysurus sp.
Illænus sp.
Raymondaspis limbatus (Angelin).
Lichas sp.
Cyrtometopus cf. *clavifrons* (Dalman).
Conchoprimitia sp.
"Tetradella" sp.
Acrotreta sp.
Lingulella lepis.
Lingula sp.
Obolus sp.
Orthid.
Eostrophomena sp.
Cystoide fragm.

This fauna occurs commonly through the whole mudstone except that the lowermost big limestone lenses with pseudomorphoses are poor in fossils. The fossil fauna and the lithology indicate that the two upper subzones of the Lower Didymograptus zone at Heramb, Ringsaker correspond with the Planilimbata beds in Sweden. In the thin nodular limestone bench at the bottom of the Orthoceras Limestone (3c) several specimens of *Megalaspis limbata* (Boeck) and

Nileus armadillo (Dalm.) were found. These fossils show that the junction between the Lower Didymograptus Zone (3b) and the Orthoceras Limestone (3c) at the locality Heramb has to be drawn between the grey mudstone and the nodular limestone bench.

The lowermost subzones of the zone 3b are not exposed at the locality Heramb. From another locality farther north in the same parish, Strand (1929, pp. 326—27) mentions that the transition from the Ceratopyge Limestone ($3a_\gamma$) to the 3b shale is also continuous, with a green or grey shale between the typical Ceratopyge Limestone and the graptolite shale. The fauna in the limestone lenses suggests that these layers may be correlated with the upper part of the Ceratopyge Beds and with the lowermost subzone of 3b or a part of it near Oslo. At the same locality Brøgger (1882, p. 19) found *Phyllograptus angustifolius elongatus* Bulman in a typical graptolite shale. In a road cut in the field north-east of the farm Mæhlum I found the same species in a light grey shale lithologically quite different from the mudstone at Heramb. As no bigger overthrusts occur within the mapped district, the above mentioned conditions must be due to local variations of facies.

The trilobites of the Lower Didymograptus Zone of the Oslo Region are described below (p. 156).

Notes on the sediments.

At the locality Heramb, Ringsaker the passage from black graptolite shale (Lower Didymograptus Shale) to the overlying massive limestone (Orthoceras Limestone) is gradual with no signs of unconformities. The succession is from below:

Black shale with big pyrite concretions (0—0.35 m).
Speckled shale } 0.35—0.50 m.
Grey shale }
Mudstone with interbedded limestone lenses (0.50—2.00 m).
Nodular limestone bench.
Limestone benches alternating with arenaceous shale (Orthoceras Limestone).

The black shale (black streak) contains large pyrite concretions The speckled shale is of the same type as that described by Henningsmoen (1949, p. 381) from Ordovician beds at Kinnekulle in Sweden, and indicates that this is a common rock type at the transition from black shale facies to more "ventilated" sediments. Above the speckled shale we have an alternation of thin layers of light and dark shale. A similar alternation is previously mentioned by Størmer (1937, p. 276) in the lowermost part of the Lower Didymograptus Shale near Oslo, and in recent sediments by Strøm (1936). These transitional layers are succeded by a grey shale and this again by a grey-green mudstone with interbedded limestone lenses containing small glauconite grains and well rounded quarts grains. Large scattered lenses with pseudomorphoses after gypsum crystals near the bottom are followed by smaller, more numerous lenses arranged in layers and finally near the massive Orthoceras Limestone united into a nodular limestone bench. The Orthoceras Limestone is developed as a thin-benched limestone. The limestone benches are separated by thin sandy shale layers. The section at Heramb thus demonstrates in the most typical way a gradual change from unventilated to ventilated bottom conditions. This is also expressed in the transition from planctonic (graptolite) to bentonic (trilobite) faunal assemblages.

Correlation of the Lower Didymograptus Zone (3 b) and corresponding deposits in Scandinavia.

When correlating the 3 b sediments one may distinguish between several types of deposits. Combinations of and transitions between the facies types listed below occur.

Euxenic facies. Black shale facies with planctonic fossils, mainly graptolites.
Mixed facies lithologic and faunistic. Planctonic and bentonic fossils.
Limestone facies with trilobites as the dominating group of fossils.
Littoral facies. Conglomeratic and sandy sediments.

In Norway, the black shales of this age have their most typical development in the vicinity of Oslo (Monsen, 1937) and their main distribution is from Oslo and northwards to Hamar at Mjøsa where the zone 3 b is of nearly the same type and thickness as close to Oslo. A little farther to the north we have a mixed facies as described from the locality Heramb in this paper. From Skartligrenden, Snertingdal on the western side of the lake of Mjøsa, Münster (1901, p. 31) mentions sandy shale with interbedded limestone lenses of 3 b age. The sandy material suggests near-shore sedimentation with sediment-yielding land to the west. In Engerdal the 3 b and underlying Cambro-Ordovician beds are missing and the upper part of the Orthoceras Limestone rests with a transgressional conglomerate on Eocambrian rocks viz. the Red Sparagmite or the Moelv Sparagmite (Holtedahl, 1921, p. 26). From Oslo and westwards the thickness of the 3 b sediments decreases (Brøgger, 1882, p. 19). The black shales at some places near Oslo have a thickness of about 24 m. Corresponding layers at Eiker have a thickness from 2—7 m. From the locality of Kårtveitbekken, Eiker, Brøgger mentions a 0.8 m thick limestone bench in the 3 b shale. At first he suggested (1882, p. 19) that this bench belonged to the lowermost part of the Lower Didymograptus Shale. Later, however, (1886, p. 41) he corrected this and referred the limestone bench to the upper part of the same zone. From the limestone bench Brøgger lists the following fossils:

Megalaspis stenorachis Angelin (?).
—»— *heroides.*
Niobe læviceps Dalm.
Ceratopyge forficula Sars.

The specimens referred to *M. stenorhachis* by Brøgger most probably should be assigned to *Megalaspis planilimbata* Angelin, (see discussion of these species below). *Magalaspis heroides* Brøgger is quoted from the Planilimbata Limestone in the North Baltic district (Wiman 1906 a, p. 91). The occurrence of these species at Krekling shows that the limestone bench represents the Planilimbata Limestone. *Ceratopyge*

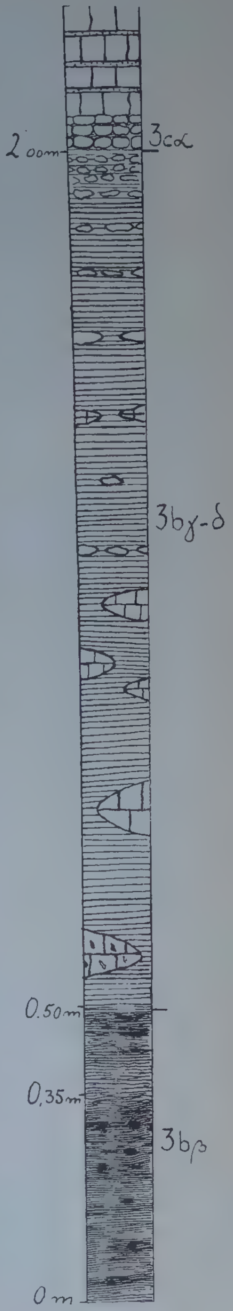


Fig. 3. The 3 b section of Heramb, Ringsaker.

forficula was reported from the same bench. This species is not present in Brøggers old collection from that locality. Until further material is available, the occurrence of this species is uncertain. West of the last mentioned locality the conditions are highly variable and the zone 3 b thins out and disappears at some localities. In the vicinity of Langesund the zone 3 b as well as the Ceratopyge series are missing and the Orthoceras Limestone rests upon Cambrian alum shale (zone 2 d) (Brøgger, 1884, p. 259).

In Sweden the same types of sediments occur, as pointed out by Moberg (1911) and Törnquist (1913). The black shales are distributed from Scania in the south across Västergötland to Jämtland in the north. They have their greatest thickness in Scania where the same sub-zones are developed as mentioned from the vicinity of Oslo (Monsen, 1937, p. 217). In Scania the 3b sediments decrease in thickness from west to east. In Bornholm we have an eastern parallel to the Langesund area in Norway. Here the Orthoceras Limestone is deposited on Ceratopyge beds. The so-called Umbonata Limestone is interpreted as a transitional layer between the Planilimbata Limestone and the Limbata Limestone (Poulsen, 1936). In Öland the limestone facies is represented by the Planilimbata Limestone(Moberg 1891, Regnéll 1939 and 1942). The tendency of decreasing thickness from west to east is best seen from Västergötland and eastwards (Thorslund 1938). In Västergötland the black shales have their greatest thickness (Westergård 1943, p. 61). Eastwards, mixed facies (Västergötland, Westergård, 1928, pp. 41—43 and 1931, p. 55), limestone facies (Östergötland, Westergård, 1940) and shallow water facies are developed. In Gotland the 3b sediments as well as the underlying Dictyonema-Ceratopyge beds and the lower part of the Orthoceras Limestone are absent (Thorslund 1938, p. 33). From Skattungbyn in Dalarna (Dalecarlia), Holm (1882, pp. 4—16) describes a section through the Lower Didymograptus Shale of nearly the same type as that described from Heramb in this paper, representing the mixed facies. The reports on the 3b deposits in Jämtland are insufficient. Black shale facies and limestone facies are mentioned from that area (Thorslund 1940). The black shales have their greatest thickness in the allochthonous both here and farther north in Västerbotten (cf. Kulling, 1942, pp. 53—54). The deposits of this age thin out towards the "Precambrian land" in the east.

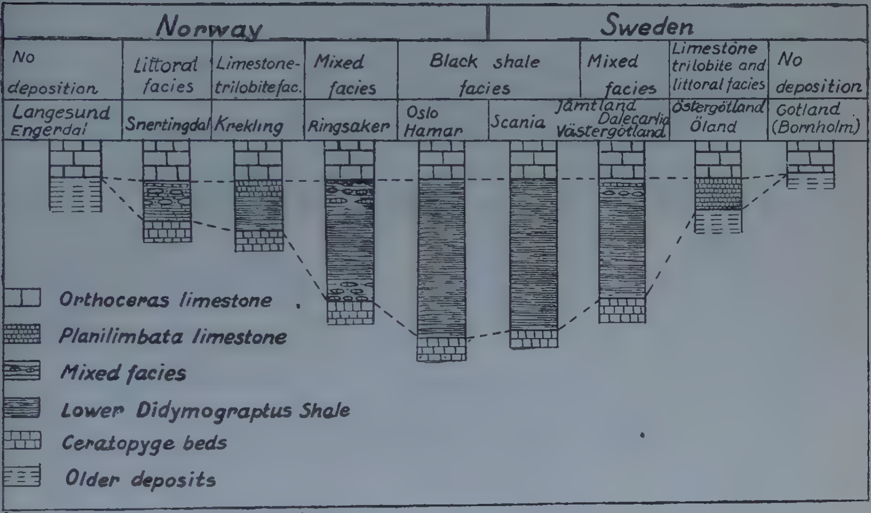


Fig. 4. Diagrammatic sections indicating the different facies of the Lower Didymograptus Shale, and the relative thickness of the sediments.

The different facies of the 3b sediments have a rather regular distribution in central Scandinavia. An attempt to draw a paleogeographic map from 3b time is shown in fig. 5. Paleogeographic maps from Scandinavia have previously been given by Holtedahl (Lower Ordovician, Dictoyonema time, 1920, p. 6, fig. 3) and by Frebold (1927).

The black shales (graptolite facies) are limited to an area from Oslo to Mjøsa and further to Västerbotten, Jämtland, Västergötland and Scania. This facies interfingers with the trilobite-limestone facies viz. the Planilimbata Limestone at Krekling, Närke, Östergötland and Öland. This facies is again surrounded by sandy and conglomeratic deposits nearer to land in Snertingdal and Östergötland. The 3b deposits are limited by areas of no deposition of that age at Langesund, Engerdal, Gotland and Bornholm.

From the distribution of the 3b sediments one arrives at the conclusion that the sediments were deposited in a more or less enclosed basin on the epicontinental platform in central Scandinavia. The extension of this basin appears from the map where the 3b deposits are marked off. The black shales have their distribution in the middle of the basin. They may be followed continuousely within the Oslo Region. In Sweden, the outcrops of the Paleozoic are too scattered to give sufficient information about the connections between them. On the flanks of the basin the black shales interfinger with limy deposits, mixed facies and limestone-trilobite facies which, in turn, grades into the sandy and conglomeratic deposits near to land. The boundaries of the basin are indicated by localities with no deposition.

A land area must have existed west of the Oslo Region in 3b time. The extension of this land area which we may call the "Telemark Land" is seen from quartzites on Hardangervidda, probably corresponding to the Lower Didymograptus Zone (Vogt, 1928, p. 100). The "Telemark Land" seems to have emerged during most of the Paleozoic, and have influenced the facies lines of Ordovician and Silurian deposits as previously indicated by Holtedahl (1909, p. 73) for the Middle Ordovician sediments and by Kiær (1906) for Silurian deposits of the Oslo Region.

To the north-west, the Caledonian movements have later changed the extension of the basin. In Ringsaker and in Jämtland—Västerbotten the Cambro-Silurian has been thrusted south-eastwards over authocthonous deposits.

The graptolites show that the above mentioned basin had free connection with the open sea during 3b time. This connection is most likely to be found to the south near Kattegat. Further connections with the Caledonian geosyncline are indicated by the graptolites at Bratland, Gausdal, and in the north of Sweden. The development of the 3b sediments in Scandinavia may throw some more light upon the problem of the black shale. The black shales suggest sedimentation farther from land than the other facies which occur. In the middle of the basin there seems to have been badly ventilated water and conditions intolerable to a bottom fauna. The black shales contain only planctonic fossils, mainly graptolites. On the flanks of the foul water the conditions altered from foul to fresher water as indicated by the mixed fauna here. The graptolites can occasionally be followed

---

Fig. 5. Map showing the distribution of the Lower Didymograptus Shale (3 b) and contemporaneous depositions in Scandinavia (based on different authors). Shaded areas suggesting the distribution of black shale (graptolite-facies). 1. Langesund, 2. Krekling, 3. Oslo, 4. Snertingdal, 5. Ringsaker, 6. Hamar, 7. Engerdal, 8. Jämtland, 9. Dalarne, 10. Limön, 11. Närke, 12. Västergötland, 13. Östergötland, 14. Öland, 15. Gotland, 16. Skåne, 17. Bornholm, 18. Hardangervidda, 19. Gausdal.

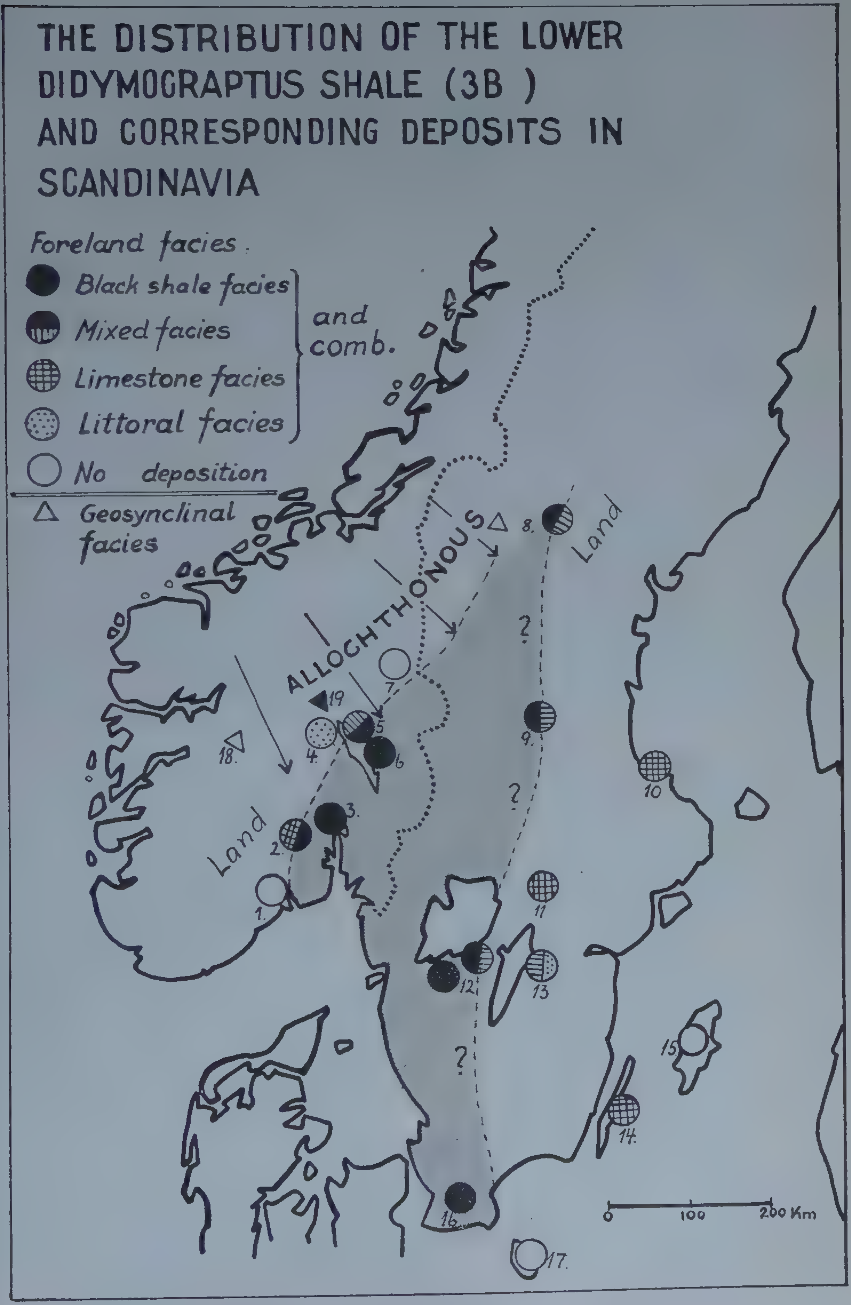

THE DISTRIBUTION OF THE LOWER DIDYMOGRAPTUS SHALE (3B) AND CORRESPONDING DEPOSITS IN SCANDINAVIA
Foreland facies :
Black shale facies
Mixed facies
Limestone facies
Littoral facies
and comb.
No deposition
Geosynclinal facies
ALLOCHTHONOUS
Land
Land
?
?
?
1.
2.
3.
4.
5
6
7.
8.
9.
10
11
12
13
14.
15.
16.
17.
18.
19
0
100
200 Km

Fig. 5.

from the black shales into homotaxial deposits (Ringsaker, Öland). The limestones with trilobites were deposited in more shallow and fresher water permitting a rich bottom fauna.

The close connection between Oslo and Scania seems to have been established in early Paleozoic time. In Middle Cambrian (Ölandicus stage) a land area is indicated in both areas (cf. Henningsmoen, 1952). The whole area was probably covered by water during the rest of the Cambrian period and still subsided during 3 b time. After this time the conditions became more uniform and at most places the Orthoceras Limestone was deposited also at places where the 3b sediments are missing, the limestone thus representing a transgressional "zone". The more or less foul bottom conditions that prevailed in 3b time in the middle of the basin had been supplanted by conditions favourable to bottom life. A new graptolite shale, the Upper Didymograptus Shale (4aα), was deposited in the Oslo Region above the Orthoceras Limestone. East and north of this Region deposition of limestone progressed. We have again nearly the same conditions as in the 3b age. The connection between Oslo and Scania is detectable in Ordovician-Silurian sediments. The connection is most likely due to the structures of the Precambrian rocks. It is a question of whether the similar Permian tectonics in the two areas may perhaps be attributed to the same cause or not.

The abrupt shift of lithofacies, from black shale (3b) to limestone (3c) near Oslo has been interpreted as a break in the sedimentation (a hiathus) (Holtedahl 1920, pp. 27—28). This assumption was based on the sequences at Langesund and Engerdal, Trysil (cf. Holtedahl, 1920, pp. 27—28). From the last mentioned locality Vogt (1928, p. 99) suggests the name "The Trysil emergence". This name is later used by Kautsky in his correlation table (1949, Beilage 1). This emergence introduces the "revolution history" of the Caledonids and should be essentially epirogenetic (Vogt, 1928, p. 144). The faunistic and lithologic transition from 3b to 3c at several localities does not indicate a break at this stratigraphical level. Movements of epirogenetic nature went on during most of the Paleozoicum in the epicontinental platform in Scandinavia. The movements are of shifting duration and intensity and vary from place to place. Caution must therefore be shown when basing correlations over wider areas on local conditions.

In the 3b age elevations took place on the flanks of the basin mentioned above. At the same time a slight subsidence took place in the middle of the basin. The Orthoceras Limestone is developed as a transgressional layer (Langesund, Engerdal). This transgression most likely coincides with the "Trondheim Disturbance". A hiathus of shorter duration is thus probably present in most places in Scandinavia in the upper part of the Orthoceras Limestone (3c).

The Planilimbata Limestone. "The Planilimbata Zone".

The Planilimbata Limestone comprises the lowermost part of the Orthoceras Limestone (3c). The Planilimbata Limestone, however, may easily be confused with certain varieties of the Ceratopyge Limestone from which it does not seem to be distinctly separated. (Moberg, 1890, p. 12). The boundaries of the Planilimbata Limestone have been much debated and Regnéll (1939, p. 2), suggests that it perhaps does not merit a segregation as a separate zone. According to Moberg the Planilimbata zone, or a part of it, belongs to the Ceratopyge series. (Moberg & Segerberg, 1906, p. 43). The series of layers between the Ceratopyge- and the Limbata Limestones are rather non-homogenous faunistically; the lower part is close to the Ceratopyge series while the upper part has to be considered as a more independent laper (Regnéll, 1939, p. 2).

The uncertainties regarding the Planilimbata beds are mainly due to the different facies of the sediments. The boundaries of the Planilimbata layers must be founded upon a thorough study of the faunal assemblage in the limestone facies. Investigation of this fauna has to be carried out in areas with continuous deposition of limestone of uniform lithologic character. When this investigation have been carried out, the Planilimbata beds may perhaps be shown to constitute a true faunizone, based on the vertical range of a selected assemblage of fossils. The Planilimbata beds at most places represent a teilzone. According to Moore (1948, p. 313): "The teilzones are defined in terms of a chosen genus or species, rather than an assemblage of fossils. The stratigraphic span of teilzones is not determined by the relative abundance of the guide fossils, depending on local differences in range, it may vary from place to place." The lower boundary of the Planilimbata beds in Scandinavia is, in most places, determined by the lithofacies and hence varies from place to place.

Many attempts have been made to correlate the Planilimbata Limestone with the graptolite time scale.

The Limbata Limestone has been correlated with the *Isograptus gibberulus* zone, whereas the graptolite zones with *Tetragraptus phyllograptoides* and *Didymograptus balticus* are correlated with the upper part of the Ceratopyge layers (Törnquist, 1913, p. 419). As assumed by Törnquist (l. c.), the zone with *Phyllograptus densus* is equivalent to the Planilimbata layers (Thorslund, 1938, p. 151). Investigations at Ringsaker support these assumptions. The two upper "sub-zones" of 3b have a faunal assemblage corresponding to that of the Planilimbata layers in Sweden. The Ceratopyge fauna continues up into the lower "sub-zone" (3bα) of the Lower Didymograptus Shale. When sufficient stratigraphic investigations have been effected on the Lower Didymograptus Shale and corresponding deposits, these deposits may, in the most instructive way, show how the environment controls the fossil assemblages and affects their distribution. It will be possible to follow the migrations and immigrations of faunal assemblages and at many places recurrent faunas will be present as already indicated by the fauna of the limestone benches occurring in the graptolite shales at some localities in Sweden.

Systematic description of trilobites.

The fauna in the mudstone with limestone lenses at Heramb, corresponding to the two upper subzones of the Lower Didymograptus Shale near Oslo, are closely related to the fauna of the succeeding Orthoceras Limestone, whereas the connection with the underlying Ceratopyge Limestone is much remote. This may be expected as the beds in question are separated fromt he limestone by graptolite shales representing a longer lapse of time. The Ceratopyge fauna disappeared fromt he district either by extinction or migration, and a new assemblage immigrated (most likely from the east) when the mudstone with limestone lenses was deposited. The trilobites in the mudstone in many ways introduce the younger fauna of the Orthoceras Limestone. Some of the species found seem to closely approach the ancestral stock of some of the later trilobites. Two new species of the genus *Ptychopyge* combine characters of the genera *Pseud-*

asaphus Schmidt and *Ptychopyge* Angelin, and no doubt lie close to the ancestral stock of both. *Lonchodomas volborthi* (Schmidt), the oldest known member of the genus *Lonchodomas* in Scandinavia has a close resemblance to members of the genus *Ampyx*. *Ampyx pater* Holm, is interpreted as ancestral to the younger *Ampyx nasatus*.

The described material belongs to Paleontologisk Museum, Oslo (P. M. O.)

Family *Agnostidae* M'Coy, 1849.

Genus *Trinodus* M'Coy, 1846.

Type species: — By monotopy, *Trinodus agnostiformes* M'Coy, 1846.

Trinodus glabratus (Angelin, 1854).

Pl. IV, fig. 18.

Material: — Only one well preserved pygidium.

Description: — The pygidium is sub-semicircular in outline an convex. The axis is triangular; its length is about 3/8 the whole pygidial length. The axis has a sagittal ridge so that the two first axial furrows are disconnected. The two first axial furrows turn a little backwards. The pygidium is surrounded by a narrow, flat border.

Occurrence: — Lower Didymograptus Zone, subzone 3 b, Heramb, Ringsaker.

Family *Remopleuridae* Hawle & Corda, 1847.

Genus *Remopleurides* Portlock, 1843.

Type species: — By subsequent designation of Miller (1889, pp. 565—66) *Remopleurides colbii* Portlock, 1843.

Remopleurides aff. *nanus* V. Leucht.

Pl. V, figs. 4 a, 6, 10.

(List of synonyms see Schmidt 1894, p. 88.)

Material: — Several well preserved cranidia and a larval cranidium.

Description: — The glabella is transversely oval in outline, moderately convex. The anterior width is about 1/5 the greatest width, and the anterior tongue is bent down vertically immediately in front of the eyes. The three pairs of glabellar furrows are faintly marked. The second and third pairs are at first directed forewards and then curve backwards to the palpebral furrows, the latter are deep and continue to forwards in the parallel tongue furrows and backwards in the deep occipital furrow. The occipital ring is well marked, strongly convex and has sub-parallel sides. The test of the glabella is distinctly striated. The striation is interrupted by the glabellar furrows. The tongue and the occipital ring have deep transverse striae.

Description of larval cranidium: — The glabella is circular in outline and strongly convex. The glabellar furrows are deep. The first and second pairs are nearly parallel and reach the axial furrows. The third pair occurs as deep imprints at the pre-lateral corners of the glabella near the junction between the axial and the palpebral furrows. The fixed cheeks are relatively broad, crescent-shaped and slightly convex. The palpebral furrows are deep. The eyes are large, convex and run in a convex bow around the fixed cheeks.

Remarks: — The glabellar furrows and the test of the cranidium of *R. nanus* are similar to the above described form. The anterior tongue of the form found at Ringsaker seems to be narrower and longer. I believe however, that a new species should not be founded upon the cranidium only and hence refer to it as *R.* aff. *nanus*. *R. nanus* occurs in the beds B_2—B_3 in the east Baltic. (Schmidt, 1894, u. 88).

Remopleurides sp. has been reported from the Planilimbata Limestone at several localities in Sweden. These specimens have, however, not been figured.

Family *Asaphidae* Burmeister, 1843.

Genus *Megalaspis* Angelin, 1851.

Type species: — *Megalaspis limbata* (Boeck, 1838)
(des. Miller 1889).

Megalaspis planilimbata Angelin, 1851.

Pl. I, figs. 9, 10.

(Description of the species and list of synonyms see Schmidt (1906, p. 10).)

Remarks: — Norwegian material of *Megalaspis planilimbata* has hitherto not been described. Brøgger (1882, pp. 76—77) found a form near to *M. planilimbata* in the Megalaspis zone of the Ortho-

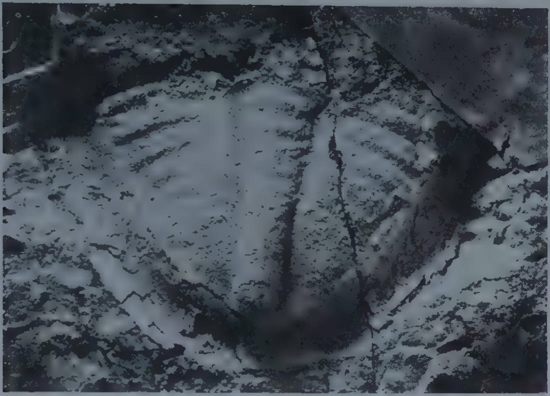


Fig. 6. Pygidium of Megalaspis planilimbata Angelin, from the upper part of the Lower Didymograptus Shale, Krekling, Eiker. (Brøgger, 1882, pl. IV, fig. 6) Brøgger coll. P. M. O. no. H. 2692. 2 ×.

ceras Limestone and also a real *M. planilimbata* in the limestone benches of the Lower Didymograptus Shale (3b). None of those specimens were brought to the Paleontological Museum. In the old collections from the Mjøsa District at the Museum I found a single pygidium most likely belonging to *M. planilimbata.* This pygidium is labelled Ottestad (the first railway station just south of Hamar). Examening the two pygidia from 3 b at Krekling, described as *Megalaspis stenorhachis* Ang. by Brøgger (1882, p. 76, pl. 4, figs. 6, 7), I find it more correct to refer them to *M. planilimbata.* I have had the opportunity to compare the pygidia with Wiman's type material from Närke (1905, p. 8, pl. 2, figs. 5—10) and see no reason why the forms from these two localities should not be conspecific. The third pygidium of *Megalaspis stenorhachis* figured by Brøgger (1882, pl. 4, fig. 5) is from the Ceratopyge Limestone at Vestfossen. It differs markedly from the two other pygidia referred to that species and may represent *M. stenorhachis* (cf. below).

Description of the pygidium from 3 b ?, Ottestad: — The pygidium is nearly semicircular in outline. The doublure border is slightly concave. The axis is narrow with a faint post-axial ridge. The pleura (8 ?) reach to the inner margin of the doublure border. The doublure is broad and extends inwards to the termination of the axis. The facets are well marked, of triangular shape, and have sharp ridges between them and the pleura. The described pygidium is exactly like one of the pygidia of this species figured by Schmidt (1906, pl. 1, fig. 2).

Dimensions: — Pygidial width 48 mm, pygidial length 31 mm, greatest width (anterior) of axis 9 mm, length of axis 25 mm.

Occurrences: — The pygidium described above occurs in a small, well rounded limestone lense which is of the same shape as the limestone lenses occuring sporadically in the upper part of the Lower Didymograptus Shale in the Mjøsa District. The lense has a typical yellow brownish weathering colour. It may be a drift boulder; but more probably it comes from the bed-rock just south of Ottestad railway station, where there is a cutting through the Orthoceras Limestone and the Lower Didymograptus Zone. The pygidia described by Brøgger (see above) occur in the upper part of the same zone in an interbedded limestone bench at Kårtveitbekken, Eiker.

A single pygidium of the species was found in the upper subzone of the Lower Didymograptus zone at Heramb, Ringsaker. *M. planilimbata* is the zone fossil of the Planilimbata Limestone in Sweden and in East Baltic.

Megalaspis stenorhachis Angelin, 1852.

1852 *Megalaspis stenorhachis* Angelin, p. 17, pl. 16, fig. 1.
1882 —»— —»— Brøgger, pl. 4, fig. 5, not 5—6.
1906 —»— —»— Moberg & Segerberg, p. 97.

This species is unsatisfactorily known. Angelins figure and diagnosis are rather insignificant according to Moberg. It seems to be much uncertainty about this species in Sweden where it is listed from the Ceratopyge Limestone, the Planilimbata Limestone and the Limbata Limestone. A redescription of the species is desirable. Brøgger figures three pygidia of *M. stenorhachis* (pl. 4, figs. 5, 6, 7). According to Moberg only Brøggers fig. 5 belongs to this species. The two others occur in the Lower Didymograptus Shale (upper part) and are in my opinion conspecific with *M. planilimbata* Angelin (cf. above).

The rachis of the pygidium narrows slightly backwards and has sub-parallel axial furrows. The segmentation of the axis is indistinct, only the first axial ring is well marked off by a deep axial furrow.

Megalaspis limbata (Boeck, 1838).

Pl. I, figs. 3, 7.

(Description and list of synonyms see Schmidt, 1906, p. 17.)

Lectotype: — P. M. O. 1631. (Brøgger, 1882, pl. 9, fig. 2), chosen by Størmer (1940, p. 141).

Material: — Several nearly complete pygidia and an incomplete cranidium.

Remarks: — The specimen found correspond to the lectotype and the type material described and figured by Brøgger (1882, pp. 77—79, pl. 9, figs. 1, 2) and most likely have to be referred to the broad variety.

Occurrence: — In the basal nodular limestone bench of the Orthoceras Limestone (3 c) at Heramb, Ringsaker. *M. limbata* is the zone fossil of the Megalaspis Limestone (3cα) in the Oslo Region. It is the first time this species is reported from the Mjøsa district.

Megalaspis ringsakerensis sp. n.

Pl. 2, figs. 1—4, 6.

Name: — From the parish Ringsaker, where the new species occurs.

Material: — Five incomplete pygidia and a hypostome.

Holotype: — P. M. O. no. 66327, pl. 2, fig. 1, an incomplete pygidium.

Other material: — P. M. O. nos. 66324, 66325, 66326, 66328.

Diagnosis: — The pygidium is nearly semicircular in outline. The axis is long with sub-parallel axial furrows which reach the inner margin of the relatively narrow doublure. The duplicated border is convex and steep. The axis has 16 axial rings. The slightly convex side lobes have 12 pleura of the *Megalaspis* type and broad shallow pleural furrows. The hypostome is of the *Megalaspis planilimbata* type, with a strongly convex middle body and unforked posterior border.

Description: — The hypostome is strongly convex. The middle body is sub-elliptical in outline. The anterior and lateral furrows deepen and widen backwards and correspond with the deep posterior furrow. The maculæ, situated just at the junction between these furrows, are directed a little forwards and run inwards into the sausage-shaped, curved, posterior lobe of the middle body. The middle furrows are deep near to the lateral furrows, but it can hardly be seen over the middle part of the hypostome. The anterior wings are strongly convex and nearly vertically placed. The anterior border in front of the middle body is narrow. The posterior wings reach forwards as far as to the middle of the anterior lobe of the middle body. The posterior border is narrow and unforked. The test of the hypostome is finely striated. The pygidium is nearly semi-circular in outline. The axis is narrow and well defined by deep axial furrows. It reaches the inner margin of the doublure where there is a crescent-shaped depression between the axis and the post-axial swollen ridge. The axis has 16 axial rings. The pleural lobes are slightly convex with the highest point a little above the depressed axis. The 12 pleuræ reach the inner margin of the doublure and are separated by broad shallow pleural furrows. The duplicated border is steep and convex. The doublure is narrow, concave and has fine terrace lines subparallel to the border of the pygidium.

Dimensions: — Length of hypostome 10 mm, width of hypostome 10 mm, length of pygidium 43 mm, width of pygidium 74 mm, anterior width of axis 11 mm, length of axis 37 mm.

Affinity: — The hypostome suggests a close affinity of the new species to *Megalaspis planilimbata* Angelin. The pygidium, however, is different from all species of *Megalaspis* described from the Lower Ordovician.

Occurrence: — Lower Didymograptus Zone, sub-zones 3 b γ-δ, Heramb, Ringsaker.

Megalaspis polyphemus Brøgger, 1882.

Pl. I, figs. 1, 2, 5, 6, 11.

Holotype: — P. M. O. no. 66419, the nearly complete specimen described and figured by Brøgger (1882, pp. 73—75, textfig. 2, 3) (see pl. I, figs. 2, 5, 6).

Material: — The holotype was till recently the only specimen of this species found in Norway. Fragments of this big *Megalaspis* has now, however, been found in the upper part of the Lower Didymograptus Zone (3 b) at Heramb, Ringsaker. In the following a redescription of the species based on the holotype and these fragments will be given.

Diagnosis: — (Brøgger, 1882, p. 72) Corpus ovatum. Caput semicirculare antice rotundatum (?) Margine excavatodepresso antcelatiore cinctum. Glabella urceolata, parum elevata, sutura faciali late circumscripta, mrginem frontalem haud attingens, long c. ¾ long. capitis totius equante. Pygidium semicirculare excedens, immarginatum, rachi antice distincte articulata, lobi lateralibus obsoletissime costatis. Long. corp. tot. pæne 0.2 met.

Description: The whole trilobite is ovate in outline and convex. The cephalon is semi-circular in outline with strong genal spines. The glabella has a shape like most of the Megalaspids, being parabolic in front. The axial furrows are broad and faintly marked. The length of the glabella is about ¾ the whole cranidial length. The occipital furrow is deep and broad near the axial furrows and relatively shallow near the median line of the glabella. The occipital lobes diverge a little forewards. The first pair of glabellar furrows occurs as deep, broad depressions between the eyes. The second and third pairs of glabellar furrows are only scarcely visible as long scars normal to the axial furrows. The width of the cranidium at the eyes equals the total length of the cranidium. The preglabellar field is broad with a rounded depression in front of the glabella. The eyes are situated far from each other on a line through the middle of the glabella. The eye ridges are narrow and diverge forwards from the eyes. The anterior branches of the facial sutures are directed forwards and outwards to the lateral margin of the head shield and then turn rapidly inwards along the margin of the shield. The posterior branches are directed straight backwards to the genal angles and then curve rapidly backwards and outwards to the posterior margin and cut this inside the genal angles. The post-marginal furrows are situated far back and are developed only from the occipital ring half way out on the fixed cheeks. The free cheeks are small, convex, and nearly vertically placed. The genal spines are broken off on the holotype. The material from Heramb shows, however, stout spines which are gently curved. The free cheeks have a flat and narrow border. The thorax has a broad axis, the width of which nearly equals the width of the inner part of the pleura. The axial furrows are well marked. The articulating halfrings and the articulating furrows are broad. The inner part of the pleura is flat, the lateral part is curved downwards almost vertically. The pleura have rounded ends. The pleural furrows are deep and reach a little out on the lateral part of the pleura.

The pygidium is sub-semicircular in outline. The posterior part is damadged in the holotype. A fragmentaly pygidium from Ringsaker shows that it is well rounded posteriorly. The axis is narrow with strong axial rings. It reaches backwards to the posterior margin of the pygidium. The pleura are only slightly developed. Wide triangular facets are situated at the prelateral corners. Inwards the facets join strong ridges in front of the first pair of pleural furrows. The doublure border is concave and steep. The doublure is narrow, concave and has fine terrace lines sub-parallel to the pygidial margin.

Remarks: — *M. polyphemus* seems to be closely related to *M. limbata* (Boeck) and its allies. It differs from the latter in several respects. The cranidium of *M. polyphemus* is much broader and shorter, its eyes are situated farther apart from each other and from the posterior margin. The facial sutures of the two species have quite different courses. In *M. limbata* the anterior branches of the facial suture are nearly parallel and then turn slightly inwards sub-parallel to the outer margin but at a good distance from it. The facial sutures of *M. polyphemus* diverge more rapidly to the outer margin and then curve sharpely inwards and run at or near the margin of the head shield. The preglabellar field seems to be more rounded anteriorly in *M. polyphemus*.

Occurrence: — Horizon and locality of the holotype is unknown. From the lithology Brøgger suggests zone 3cα, Eiker? Oslo?. The fragments of this species at Ringsaker are found in the upper subzone of the Lower Didymograptus Zone (3bδ). The holotype may also come from the same zone and probably from this or a near by locality.

Megalaspis heroides Brøgger, 1882.

Pl. I, figs. 4, 8.

Lectotype: — (chosen here) P. M. O. no. H. 2698, (Brøgger, 1882, pl. 4, fig. 3), an incomplete pygidium showing the pointed posterior end. Lower Didymograptus Zone, Krekling, Eiker. Norway.

Syntypes: — P. M. O. nos. H. 2643, 1538.

Diagnosis: — (Brøgger, 1882, p. 82) "Pygidium sub-triangulare, postice acuminatum, margine depresso cinctum. Rachis segmentis c. 14, costæ lateralis c. 10, dichotomæ, obsolætæ. Ad Krekling in stratis 3 a—3 b invenitur."

In Brøggers old collections from Krekling there is some material which permits a supplementary description of this species.

Material: — The two pygidia described and figured by Brøgger (1882, p. 82, pl. 4, figs. 3, 4), an incomplete cranidium, an external mould of a hypostome and the posterior part of a pygidium.

Description: — The glabella is retort-shaped and slightly constricted between the eyes and with rather broad, shallow lateral and preglabellar furrows. The occipital furrow is deep and broad. The occipital ring equals in width the greatest width of the glabella. The eyes are situated close to the glabella and seem to be large. The preglabellar field is broad and concave in front of the glabella, where a rather shallow, oval depression is indicated. The anterior branches of the facial suture run forwards and outwards from the eyes and then turn inwards and meet in an obtuse angle (120 degrees) rather far in front of the glabella. The anterior lobe of the middle body of the hypostome is sub-elliptical in outline and strongly convex. The posterior lobe of the middle body is narrow, sausage-shaped and well defined by the middle and posterior furrows. The posterior border is broad and seems to be pointed.

Remarks: — Brøgger (1882, p. 82) suggests that *M. heroides* is the first member in a series of closely related species, viz. *M. heroides, M. heros* and *M. acuticauda.*

Occurrence: — Upper part of the Lower Didymograptus Shale, Kårtveitbekken, Krekling, Eiker, Norway. Brøgger at first doubtfully refers the specimens from Krekling to the upper part of the Ceratopyge Limestone. Later (1886, 41) he corrects this to the upper part of the Lower Didymograptus Shale.

This species is also reported from corresponding layers in Sweden, where Wiman (1906 a., p. 91) found it in the Planilimbata Limestone at Limön.

Genus *Ptychopyge* Angelin, 1854.

Type species: — *Asaphus angustifrons* (Dalman, 1827) des Brøgger 1886, p. 32. (Later Vogdes (1890), not being aware of Brøgger's determination determined *Ptychopyge applanata* Angelin as type species.)

Ptychopyge herambensis sp. n.

Pl. III, figs. 1—8.

Derivation of name: — From the type locality Heramb, Ringsaker.

Holotype: — P. M. O. nos. 66306, 66307, pl. III, figs. 2, 3, 4. A nearly complete specimen, consisting of a fragmentary cranidium and thorax, the hypostome in situ and the pygidium. From the two upper sub-zones of the Lower Didymograptus Zone at Heramb, Ringsaker.

Other material: — P. M. O. nos. 66305, 66308, 66309, 66310.

Diagnosis: — The outline of *Ptychopyge herambensis* sp. n. is rather like that of *Ptychopyge truncata,* especially the variety *brøggeri* Schmidt. It differ from that form in several features.

The glabella of *P. herambensis* is wider in front with a nearly straight preglabellar margin. Its hypostome is of the *P. angustifrons* type (cf. Schmidt, 1906, p. 35) and similar to the old *Ptychopyge* hypostomes described by Schmidt (1906, p. 45).

The pygidium resembles that of *P. truncata* in outline, but the doublure is narrower and has much coarser, partly furcated and disconnected, more distantly placed terrace lines.

Description: — The cephalon is sub-semicircular in outline with the genal angles drawn out into pointed genal spines. The glabella is pear-shaped. The preglabellar furrow is only a little convex forwards. A faint median ridge is visible on the glabella. There are rather deep triangular impressions on each side of the glabella at its narrowest part between the eyes. In front of these impressions one may see, especially in specimens without shell, at least two pairs of long, sausage-shaped muscle scars. The strong basal lobes diverge a little forwards and are situated in the axial furrow just in front of the occipital furrow. The ends of the occipital furrow are deep, but at the middle of the glabella the furrow becomes wide and shallow and can hardly be traced. A rather strong glabellar node is situated just in front of the occipital furrow. The eyes lie close to the glabella. The anterior branches of the facial sutures run at first nearly normal to the axial furrows, and then turn outwards and forwards to close to the lateral border of the head shield, wherefrom they are subparallel to the border and meet in an ogive in front of the glabella. The lateral and preglabellar borders are broad and flattened. The posterior branches of the suture are sub-parallel to the posterior margin. Laterally they turn sharply backwards to cut the posterior margin well inside the genal spines. The portion behind the eyes at the junction between the axial and the post-marginal furrows is swollen. The hypostome is of the *P. angustifrons* type (cf. Schmidt, 1906, p. 35). The anterior lobe of the middle body is elliptical and reaches the anterior margin of the hypostome. The lateral furrows are deep and narrow anteriorly, then they widen backwards where they end in deep depressions. In these depressions the maculæ are placed normally to the lateral furrows. The anterior wings are strong and nearly vertically placed. The posterior border is wide and forked. The lateral borders taper gradually and end on each side of the anterior part of the middle body.

One fragments of the thorax were found. The axis is relatively broad, its width being about one third of the whole thoracic width. The pleural furrows on the inner flat part of the pleura are deep and boat-shaped. The pygidium is sub-semicircular in outline and has a broad valted surrounding brim and a broad shallow furrow within this brim. The prelateral corners are rounded. The rachis is relatively narrow, its anterior width being about one fifth the whole pygidial width. The axial furrows are straight. The axis has at least eleven axial rings. The pleura (7?) are well marked off by broad shallow pleural furrows. The pleura are at first directed outwards and just a little backwards to the inner margin of the doublure and from there they turn backwards and end just inside the vaulted brim of the pygidium. The facets are large and nearly horizontally placed. Between these and the first pair of pleural furrows there are sharp projecting ridges. The doublure is broad and underlie all parts of the pygidium exept for the axis and a small triangular field on each side of the anterior part of the axis. The terrace lines are coarse, remotely placed, partly furcated and disconnected. The doublure thus is similar to species belonging to the genus *Pseudasaphus* Schmidt. The test of the pygidium has fine transverse, disconnected striæ. Across the axis the striæ curve forwards and mark the axial rings.

Varieties: — Together with the form described above there occurs a longer variety which in all other respects is quite similar to *Ptychopyge herambensis* sp. n.

Occurrence: — Lower Didymograptus Zone (3 b δ γ) Heramb, Ringsaker.

Ptychopyge minor sp. n.

Pl. IV, figs. 2, 5, 8, 9.

Holotype: — P. M. O. no. 66311, pl. IV, fig. 2, a complete pygidium and the hindermost part of the thorax, from the Lower Didymograptus Zone, Heramb, Ringsaker, Norway.

Other material: — P. M. O. nos. 66312, 66313, 66314 from the same zone and locality.

Material: — An incomplete cranidium, thoracic segments and several complete and well preserved pygidia.

Diagnosis: — Disregarding the smaller dimensions this species resembles *P. herambensis* sp. n. It differs from that species in several ways, however. The preglabellar furrow is a little curved backwards. The pygidium is semicircular in outline. The axis is narrow with a median keel. The doublure is relatively narrow but has terrace lines of the same type as the above described speies.

Desription: — The cranidium is similar to that of *Ptychopyge herambensis* sp. n. The preglabellar furrow is slightly curved backwards. The depression in the glabella between the eyes is deep. The hypostome is still not known. The axis of the thorax is narrow and slightly carinate and its width equals the width of the inner flat border of the pleuræ. The thoracic segments are narrow. The part inside the fulcrum is flat. The lateral part of the pleura curve downwards nearly vertically. The pleural ends are pointed and directed a little backwards. The pleural furrows are narrow and reach the fulcrum. The pygidium is semicircular in outline. The axis is narrow with a longitudinal median keel, and the anterior width is one fifth to one sixth of the pygidial width. The pygidium has the same vaulted brim as *P. herambensis* sp. n. The axis has at least eleven axial rings. The side lobes are slightly convex with seven pleuræ which curve backwards to the inner margin of the vaulted brim. The faint pleural furrows are distinct inside the inner margin of the doublure. From this margin and outwards the pleura become wider. The doublure is narrower than in *P. herambensis* sp. n. The terrace lines and the test of the pygidium are similar to those in the last mentioned species.

Dimensions: — Width of pygidium: 9—20 mm, length of pygidium 4.5—10.5 mm, greatest (anterior) width of axis 1.5—3.5 mm, length of axis 4—9 mm.

Ptychopyge minor sp.n. seems to be closely related to *P. herambensis* sp.n. Disregarding the great difference in size the similiarities between those species are striking. The outlines of hte pygidia are, however, different.

The pygidium of *Ptychopyge excavato-zonata* (Angelin) is very nearly semicircular in outline. Furthermore it has the same vaulted brim with furrow inside as the two new Norwegian species.

The type material of "*Megalaspis*" *excavato-zonata* (Angelin 1854, pl. 29, fig. 4) was examined and is figured in the present paper (pl. IV, fig. 1). Its axis is different from *P. minor* sp.n. The anterior axial width is one third to one fourth of the pygidial width. The median line of the axis is straight in *P. minor* sp.n. but it is concave in *P.excavato-zonata*. Brøgger (1886, p. 33) proposed the name *Ptychopyge cincta* for the latter species. This name was latter used by Lindström (1901, p. 69) and by Schmidt (1906, p. 46). Angelin's name *excavato-zonata* has to be used for this species according to the rule of priority.

Occurrence: — Lower Didymograptus Zone, upper subzones, Heramb, Ringsaker, Norway.

Ptychopyge sp.

Pl. IV, fig. 7.

This fragmentary cranidium is from the upper part of the Lower Didymograptus Shale, Krekling, Eiker. (Brøgger coll. 1882).

Genus *Niobe* Angelin, 1852.

Type species: — *Asaphus frontalis* Dalman, 1827 (det. Vogdes 1890).

Niobe læviceps (Dalman) 1827.

Pl. II, figs. 5, 11, 12.

1901. *Niobe læviceps* Schmidt, p. 103—105, pl. 10, figs. 5, 6.
1906. —»— —»— Moberg & Segerberg, p. 96, pl. 6, figs. 17—18, pl. 7, figs. 24.

Material: — A nearly complete cranidium and several well preserved pygidia.

Description: — The glabella has its greatest width just in front of the eye lobes and tapers gradually backwards. It is a little rounded in front. The small glabellar node is situated just behind the eyes. The occipital furrow is shallow. The occipital lobes are long and nearly parallel to the axial furrows. The pre-glabellar field is flat and narrow. The pygidium is sub-semicircular in outline and slightly drawn out at the post-lateral corners. It is surrounded by a slightly vaulted border which has its greatest width at the post-lateral corners. The axis is triangular in outline. On specimens without shell one may count 8 axial segments. The ring furrows are curved, first forwards and then backwards. A strongly developed post-axial ridge tapers gradually backwards and end just at the inner margin of the flattened vaulted border. Specimens without shell show well marked pleura, reaching the inner margin of the doublure. The duoblure is broad and reaches the termination of the axis leaving only a triangular field on each side of the axis free. The terrace lines of the doublure are well marked and forked. The test of the pygidium shows a fine striation and a fine punctuation. The articulating half ring and the facets are large.

Occurrence: — Lower Didymograptus Zone (3 b) Heramb, Ringsaker. When discussing the succession of the species of the genus *Niobe*, Brøgger (1886, p. 52) interprets *Niobe læviceps* as a zonal fossil for the Lower Didymograptus Shale (3 b).

Genus *Nileus* Dalman, 1827.

Type species: — *Asaphus armadillo* (Dalman, 1827) d. Miller, 1889.

Nileus armadillo (Dalman, 1827).

Pl. II, figs. 7, 8, 11.

N. armadillo is one of the most common trilobites in the upper subzone of 3 b at Heramb, Ringsaker.

Nileus limbatus Brøgger, 1882.

Together with the last mentioned species there are small pygidia agreing with Brøggers type material of *N. limbatus*. This species is also reported fromt he Planilimbata Limestone in Sweden.

Genus *Symphysurus* Goldfuss, 1843.

Type species: — *Asaphus palpebrosus* Dalman, 1827,
d. Barrande, 1852.

Symphysurus sp.

Pl. IV, fig. 13.

The figured pygidium is from the upper sub-zone of 3b, Heramb, Ringsaker.

Family *Styginidae* Vogdes, 1893.

Genus *Raymondaspis* Pribyl, 1948.

(Whittington (1950, p. 549) gives the synonyms of this genus.)

Type species: — By subsequent designation of Miller, 1889, p. 550: *Holometopus limbatus* Angelin, 1854.

Raymondaspis limbatus (Angelin, 1854).

Pl. IV, figs. 16, 17, 19, 20, 21.

1854. *Holometopus limbatus* Angelin, p. 58, pl. 33, figs. 7.7 a.
1906. —»— —»— Wiman, pp. 293—94, pl. 29, figs. 21—22.
1950. *Raymondaspis* —»— Whittington, p. 549, pl. 72, figs. 11—14.

Material: — An incomplete external mould of a cranidium and two complete and well preserved pygidia.

Description: — The cephalon seems to be sub-semicircular in outline. The glabella is convex. It is narrow with deep axial furrows, concave inwards. The narrowest part of the glabella is between the eyes at the first pair of glabellar furrows. This pair is triangular in outline with the apex of the triangle directed outwards touching the axial furrows. The two first pairs are smaller, circular in outline and scarcely visible. The occipital ring is well marked by a deep axial furrow and has a neck tubercle. The eyes are situated far from the glabella. The eye ridges are relatively long and run from the eyes forward to the second pair of glabellar furrows. The test of the cranidium has a very fine striation; on the cheeks concentric around the eyes and on the glabella and the occipital ring concentric around the occipital furrow and the neck tubercle. The pygidium is subsemicircular in outline, the width is a little more than twice the pygidial length and the height about one third the length. The axis is narrow, in front about one sixth the pygidial width. The axial furrows are deep. The axis reaches to the inner margin of the doublure, but is connected with the posterior margin by a lower and narrower postaxial ridge. Only the first axial ring is well marked off by a relatively deep ring furrow. The next rings (6?) are scarcely visible, The side lobes are convex. The duplicated border is concave. The doublure is broad and reaching inwards as far as to the termination of the axis. The facets are large and nearly vertically placed. The articulating halfring is strong. The test of the pygidium hast he same fine striation as the cranidium.

Remarks: — While discussing the genus *Raymondaspis,* Whittington (l. c. p. 550) calls attention upon the material of *R. limbatus* from Borghage, Öland, Sweden, described and figured by Wiman (1906 a, pp. 293—94, pl. 29, figs. 21—2). "The pygidium is similar in outline and convexity to the topotypes of *R. limbatus,* except that the duplicated border in Wimans examples is concave, not convex and steeply sloping. It therefore seems that Wimans species is not conspecific with *R. limbatus.*" Examening Angelin's figs. 7 and 7 a (1854, pl. 33) it seems to me that both cephalon and pygidium of *R. limbatus* are pictured with concave duplicated border by him. The incomplete cranidium and the two pygidia described above agree quite well with the figures of Angelin's *"Holometopus" limbatus.*

Occurrence: -- Lower Didymograptus Zone (3bγ-δ) Heramb,

Raymondaspis limbatus is one of the zone fossils of the Planilimbata Limestone in Sweden. It is reported from this limestone in Öland (Moberg, 1891, p. 12), Västergötland (Thorslund 1938, p. 156), Östergötland (Westergård, 1940, pp. 29—30), Närke (Westergård, 1940, p. 44), N. Balticum (Wiman, 1906, p. 98). The species is also reported from the Limbata Limestone in Sweden.

Trilobite sp. *(Styginid ?).*

Pl. IV, fig. 12.

This undetermined pygidium is from the subzone 3bγ, Heramb, Ringsaker.

Family *Cheiruridae* Salter.

Genus *Cyrtometopus* Angelin, 1854.

Type species: Calymene clavifrons Dalman (det. Barton, 1920).

Cyrtometopus cf. *clavifrons* (Dalman, 1826).

Pl. IV, figs. 3, 4, 6.

(For list of synonyms and description of species see Schmidt (1881, p. 153) and Brøgger (1882, p. 131).

Material: — Some fragmentary cranidia and an incomplete pygidium.

Description: — The cephalon is sub-semicircular in outline with short, strong genal spines directed backwards and slightly outwards. The glabella is egg-shaped, strongly convex and bordered laterally by deep axial furrows. It has its greatest width near the second pair of glabellar furrows and is rounded in front. The glabellar furrows are deep. The second and third pairs are directed normal to, or a little backwards from the axial furrows. They are slightly curved, extending about half way from the axial furrows to the median line of the glabella. The first pair of the glabellar furrows is directed oblique inwards and backwards. It is deeper than the others for the greater part of its length, the inner ends becoming shallower and bending strongly backwards to the occipital furrow. The cheeks are slightly convex, sloping downwards laterally and anteriorly, where they are bordered by a deep continuous marginal furrow and a well defined, rounded marginal border. The genal angles taper gradually into the genal spines. The eyes are small. The anterior branches of the facial suture converge slightly forwards to the lateral border. The posterior braches run from the eyelobes sub-parallel to the posterior margin of the cheeks and curve a little backwards before they cut the lateral margin. The surface of the cheeks inside the marginal furrows are covered by rounded pits. The pygidium is sub-semicircular in outline. The axis is convex with four sharpely defined axial rings and ring furrows. The side lobes have three or four pleura of which at least the anterior and the second have free ends. The anterior pair is the largest in width and length, with outer ends reaching beyond the following pairs. Near to the axis it has deep median pleural furrows. The free ends of the 2. pair are short and directed backwards. The posterior ring of the axis is almost hidden between the ends of the 2. and the 3. pairs.

Remarks: — *C. clavifrons* has formerly been described from the Norwegian Orthoceras Limestone (Brøgger, 1882, p. 131, pl. 5, figs. 1—9). Brøgger here figured a pygidium of the species (pl. 5, fig. 9). The figure is, however, according to himself "nicht gelungen". The above described form from the upper subzone (3 b δ) Heramb, Ringsaker, is like the species described by Brøgger (l. c.) from a somewhat higher zone.

Family *Lichadidae* Corda.

Genus *Lichas* Dalman, 1827.

Type species: — By monotypy, *Entomostracites lacinatus* Wahlenberg, 1821.

Lichas sp.

Small fragments of a pygidium belonging to a *Lichas* occure in the upper part of 3 b at Heramb, Ringsaker. A *Lichas* sp. of nearly the same age from Grönviken, Öland, Sweden, was described and figured by Regnéll (1942, pp. 14—15, textfig. 7). That specimen was found in layers belonging to the Planilimbata zone or the Limbata zone and is according to Regnéll the oldest representative of the Lichadidae hitherto found in Sweden. The pygidial fragments of the *Lichas* sp. from Ringsaker have a fine surface granulation. As only fragments occur in Ringsaker a comparation of the two old Lichaddiae from Sweden and Norway is at present impossible.

From Tremadocian beds in Bohemia, Ruzička (1926, pp. 14—15) describes a new species, *Lichas kloučeki* founded upon a pygidium. The pygidium shows a close resemblance to the specimen described by Regnéll.

Family *Ceratopygidae* Raymond, 1927.

Genus *Ceratopyge* Corda, 1847.

Type species: — *Olenus forficula* Sars, 1835.

Ceratopyge forficula (Sars, 1835).

Pl. IV, figs. 10, 11, 14, 15.

Lectotype: — P. M. O. coll. no. 4269 a. (chosen by Størmer, 1940, p. 127).

Hypotypoids: — P. M. O. nos. 56197 b, 56199 (l. c., p. 127).

Strand found this species in the lowermost part of the Lower Didymograptus Shale (grey shale with limestone lenses) at the locality Sten, Ringsaker. In the old collections at the P. M. O. I found a rock sample with plenty of fragments of *Ceratopyge forficula,* from that locality. Among the fragments is a rather broad variety of *C. forficula* which may represent a new species of the genus *Ceratopyge.* Brøgger (1882, pp. 123—24) gives a detailed description of *C. forficula,* and mentions variation of the species *C. acicularis* Boeck and *C. lyra* Boeck are by. Brøgger interpreted as variations of one and the same species viz. *Ceratopyge forficula* Sars. As long as the varieties of this species from the Ceratopyge beds is too little known, I suppose it is the best to interpret the specimens from the Lower Didymograptus Shale, Ringsaker as variety of *C. forficula.*

The hypostome of this well known species is undescribed. It occurs, however, in the above mentioned limestone lens from the zone 3 b, Sten, Ringsaker. In the fossil collections at the P. M. O. from the Ceratopyge Limestone I found supplementary material which enables me to give a nearly exhaustive description of it.

The hypostome is sub-elliptical in outline. The middle body is elliptical and strongly convex. A faintly marked, shallow middle furrow is indicated. This separates the anterior lobe and the rather narrow posterior lobe. At the lateral ends of the middle furrow they widen. Here the maculæ are situated. The anterior wings are relatively broad and nearly vertically placed. The anterior border is narrow. The posterior brim tapers gradually forwards and ends half way up on each side of the anterior lobe. The posterior brim has a faintly indicated bifurcation. Together with the typical hypostome occurs a shorter and broader hypostome of the genus *Ceratopyge.*

This hypostome most probably belongs to the broad variety of *C. forficula* mentioned above.

Remarks: — The hypostome *of C. forficula* shows a close similiarity to those of early represents of the family *Asaphidae* (as illustrated by Westergård, 1939) and the later occurring genus *Megalaspis,* thus indicating relationship between these families.

Occurrence: — *C. forficula* (Sars) is one of the zonal fossils in the Ceratopyge beds in Scandinavia. According to Strand it also occurs sporadically in the lowermost part of the zone 3 b in the Mjøsa district. Brøgger (1882, p. 76) mentions a find of the species in the upper part of 3 b at Eiker. I have examined Brøggers material from that locality and have not found the species. For the present it seems most probable that the vertical distribution of *C. forficula* is limited to the Ceratopyge beds (the shale and the limestone (3 a β—3 a γ)) and to the limestone facies of the lowermost sub-zone of the Lower Didymograptus Shale (3bα).

Family *Raphiophoridae* Angelin, 1854.

Genus *Ampyx Dalman, 1827.*

Type species: — By monotopy, *Ampyx nasutus,* Dalman, 1827.

Ampyx pater Holm, 1882.

Pl. V, figs. 2, 4 b, 7, 12, 13, 14, 15, 16.

Lectotype: — (Chosen here) R. S. no. A_2 9254, figured by Holm 1882 as figs. 13, 14, p. 16. An incomplete cranidium from the Lower Didymograptus Shale, Skattungbyn, Dalarne, Sweden.

Syntypes: — R. S. nos. A_2 9256, A_2 9254?.

Diagnosis: — Holm (1882, p. 12) gives the following diagnosis of the species: "Der Kopfschield bildet, abgesehen von der Glabella ein Segment eines Kreises. Die Glabella hoch, gewölbt, nicht gekielt, aber hinten an den Seiten etwas zusammengedrückt, nach hinten hin gleichmässig sich verjungend, mit ihrem freien Theile ungefähr $^1/_3$ der ganzen länge der Glabella ausserhalb der Vorderkante des Kopfschildes hervorragend. Die Spitze der Glabella abgerundet, mit einem schmalen Rostrum versehen. Der Nackenring ziemlich schmal, sowie auch die erhohte Linie, welche die hintere Kante der Wangen bildet."

Törnquist (1884, p. 87) gave an additional description of the species from the type locality. The glabella is provided with a narrow rostrum which is longer than the glabella. From fragments he suggested that the genal spines are long and gently curved. The pygidium is short, rounded, triangular in outline with a nearly straight anterior border. The axis reaches near to the border of the pygidium and has at least three axial rings.

Thanks to the obligingness of Professor Stensiö, Stockholm, I have had the opportunity to compare the specimens of *Ampyx* collected in the Lower Didymograptus Zone at Heramb, Ringsaker, with Holms type material from Skattungbyn (see pl. V, figs. 14, 15, 16). There seems to be no doubt as to the conspecificity. As the type material is deficient I will give a rediscription of the species based on material from Heramb, Ringsaker (several well preserved cranidia and genal spines.)

Description: — The cephalon, excluding the glabella and frontal spine, is sub-triangular to semicircular in outline and has long and curved genal spines. The glabella is pear-shaped and strongly convex. The front of the glabella is rounded and bears a long curved frontal spine which is circular in cross section. The axial furrows are fairly deep. Four pairs of muscle scars are situated adjacent to the axial furrows. The posterior pairs are large and shallow, nearly circular in outline and is situated near to the axial furrows. The anterior pair of scars is long and narrow. The two last mentioned pairs have their longest axis nearly normal to the axial furrows. The occipital furrow is broad and rather deep with a pair of small muscle scars at the outer ends. The occipital ring is narrow and separated fromt he posterior border of the cranidium by the axial furrows. An elongate pit is situated in the axial furrows on each side of the widest part of the glabella. In front of the glabella a rather deep furrow separates a flat anterior border. The fixed cheeks are convex. The suture lines cut the anterior border at a good distance from the glabella. From these cutting points the suture lines curve over the cheeks in lines concave outwards. They reach the posterior border just inside the genal spines. The suture thus is opisthoparian. The genal spines are long, curved and directed outwards and backwards. They have a deep longitudinal furrow.

Affinity: — Ampyx pater Holm seems to be closely related to *Ampyx nasatus* Dalman. The similiarities between these species are striking. It is likely that the latter has developed from *A. pater* or closely allied species.

Occurrence: — Lower Didymograptus Zone (3 b) Heramb, Ringsaker. It is one of the most common fossils in the Planilimbata Limestone in Sweden, and is listed from the localities where the Planilimbata Limestone is developed. The species was first described from the Lower Didymograptus Shale (Phyllograptus Shale) in Dalarne, Sweden (Holm, 1882, p. 12).

Genus *Lonchodomas Angelin, 1854.*

Type species: — By subsequent designation of Raymond, 1925, p. 35,
Ampyx rostratus Sars, 1835.

Lonchodomas volborthi (Schmidt, 1894).

Pl. V, figs. 1, 3, 5, 8, 9, 11.

1894. *Ampyx volborthi* Schmidt, p. 80, pl. 6, figs. 11—20.
1942. —»— Regnéll, pp. 3—4, textfig. 4.

In the 3 b mudstone at Heramb there occurs a species that agrees with "*Ampyx*" *volborthi,* and seems to be conspecific with this. The species found has a four-edged glabellar spine and has therefore to be placed in the genus *Lonchodomas.* According to Schmidt (1894, p. 77) *A. volborthi* has five thoracic segments. Therefore it seems most likely to me that Schmidt's species belongs to *Lonchodomas.* Further discussing of the above mentioned species must be postponed as the type material at present is not accessible. For the present I see no reason for introducing a new name for the species found at Heramb.

Material: — A nearly complete cranidium, fragments of cranidia and several complete and well preserved pygidia.

Description: — The cephalon is triangular to semicircular in outline. The width is more than twice the sagittal length, excluding the spine. The glabella is strongly convex, and slightly carinate. It tapers gradually into a long frontal spine, four-edged in cross section. On each side of the glabella there are three pairs of deep muscle scars. The first pair is the deepest and the glabella is narrowest just here. This pair corresponds with a pair of imprints in the occipital furrow. At the widest part of the glabella there is a pair of anterior pits. The cheeks are gently convex. The post-marginal furrow is broad and shallow, deepening outwards, ending in an elongate pit laterally. The cheeks taper gradually into the genal spines. The outline of the pygidium is like that of *A. nasatus*. It is triangular with slightly convex postlateral sides. It differs from *A. nasatus* in having a well defined edge at the inner margin of the doublure border. The axis is relatively narrow and long. It reaches the inner margin of the doublure, where the axis bends a little upwards. The axial furrows are shallow. Specimens without shell show about 20 axial rings, scarcely visible on specimens with shell preserved. The axis hast he same pairs of muscle as *Lonchodomas rostratus* (Sars) (see Whittington, 1950, pp. 556—57). The slightly curved pleura are only indicated on the convex side lobes. The test of the cranidium and pygidium has fine and closely spaced punctae. The side lobes of the pygidium have a fine striation in addition to the punctation. The doublure border of the pygidium has fine terrace lines sub-parallel to the margin of the pygidium.

Occurrence: — Lower Didymograptus Zone subzones (3 b γ-δ) Heramb, Ringsaker. The species is reported from the Planilimbata—Asaphus limestones in Öland, Sweden (Regnéll, 1942, p. 4), and from the Umbonata limestone, Bornholm, Denmark (Poulsen, 1936).

References.

Angelin, N. P., 1851: Palæontologia Suecica. Pars I. Iconographia Crustaceorum Formationis Transitionis. Fasc. I. — Pp. 1—24, pls. I—XXIV. Holmiæ.

— 1854. Palæontologia Scandinavica. Pars I. Crustacea Formationis Transitionis. Fasc. II. — Pp. I—IX, 21—92, pls. XXV—XLI; new pls. XX, XXII for the above paper. Holmiæ.

Brøgger, W. C., 1882: Die silurischen Etagen 2 & 3. Universitätsprogram 2. Sem. 1882, Kristiania.

— 1884: Spaltenverwerfungen in der Gegend Langesund-Skien. Nyt Mag. Naturvidensk., vol. 24.

— 1886: Ueber die Ausbildung des Hypostomes bei einigen skandinavischen Asaphiden. Bih. K. svenska vetensk. akad. handl. Bd. 11, no. 3.

Frebold, H., 1927: Zentren epirogener Hebung als Schwellengebiete in den paläozoischen Meeren des Baltischen Schildes und seiner randlichen Teile. Neues Jahrbuch. f. Min. 1927.

Hadding, A., 1913: Några iakttagelser från Jämtlands ordovicium. Geol. fören. Stockholm Förh. Bd. 34, H. 6.

Henningsmoen, G., 1948: "The Tretaspis series of the Kullatorp core" in: Deep boring through the Ordovician and Silurian strata at Kinnekulle, Västergötland, by Wærn, Thorslund and Henningsmoen. Geol. Inst. Uppsala Bull., vol. 32, pp. 337—474, pls. 20—26.

Holm, G., 1882: Ueber einige Trilobiten aus dem Phyllograptusschiefer Dalekarliens Bih. K. svenska vetensk. akad. hand. Bd. 6, no. 9.

Holtedahl, O., 1909: Studien über die Etage 4 des norwegischen Silursystems beim Mjøsen. K. norske Vidensk. Selsk. Oslo Forh. I. no. 7.

— 1920 a: Om Trysilsandstenen og sparagmit-avdelingen. Norsk geol. tidsskr, Bd. VI, H. 1—2.

— 1920 b: Paleogeography and Diastrophism in the Atlantic-Arctic Region during Paleozoic Time. Journ. Sci., 4. ser., vol. 49, New Haven, Conn.

— 1934: The Geology of parts of Southern Norway. Proceed. Geol. Ass., Vol. XLV, part 3.

Kiær, J., 1906: Das Obersilur im Kristianiagebiete, Eine Stratigraphische Faunistische Untersuchung. K. norske Vidensk. Selsk. Oslo Forh. B. II.

— 1916: The Lower Holmia Fauna at Tømten in Norway. K. norske Vidensk. Selsk. Oslo Forh. I, no. 10.

Kautsky, G., 1949: Stratigraphische Grundzüge im westlichen Kambrosilur der scandinavischen Kaledoniden. Geol. fören. Stockholm Förh. Bd. 71, h. 3.

Kulling, O., 1942: Grunddragen av fjällkedjerandens bergbyggnad inom Västerbottens Län. Sveriges geol. undersökning, Ser. C, no. 445. (Årsbok 36, no. 2.)

Lindström, G., 1901: Researches on the visual organs of the trilobites. K. svenska vetensk. akad. handl., bd. 34.

Moberg, J. C., 1890: Anteckningar om Ölands Orthocerkalk. Sveriges geol. undersökning, Ser. C, no. 109.

Moberg & Segerberg, 1906: Bidrag till kännedomen om Ceratopygeregionen. Medd. Lunds Beol. Fältklubb. Ser. B, no. 2.

Moberg, J. C., 1913: Historical-Stratigraphical review of the Silurian of Sweden. Sveriges geol. undersökning, Ser. C, no. 229.

Monsen, A., 1937: Die graptolithenfauna im unteren Didymograptusschiefer (Phyllograptusschiefer) Norwegens. Norsk geol. tidsskr. Bd. 16, pp. 57—266.

Moore, R. C., 1948: Sedimentary facies in geologic history. (Conference at Meeting of The Geological Society of America held in New York, November 11, 1948) Geol. Soc. of Am. Mem. 39, pp. 1—44. New York.

Münster, Ths., 1901: Kartbladet Lillehammer. Tekst. Norges geol. undersøkelse, no. 30.

Regnéll, 1939: Om faunan i Planilimbatakalkstenen vid Köping på Öland. Medd. Lunds Geol.-Min. Inst. no. 80.

Regnéll, 1942: Stratigraphical and paleontological remarks on the Lower Ordovician of Central and Northern Öland. With special reference to Köping Klin. Ibid. no. 99.

Ruzička, R., 1926: Faune des couches àEuloma du gisement ferrugineux près de Holoubkovà Ouzky. Bull. internat. de l'Academie des Sciences de Boheme.

Schmidt, F., 1894: Revision der ostbaltischen silurischen Trilobiten. Abt. IV. Mem. Acad. Imp. Sci. St. Petersbourg.

— 1907: Revision der ostbaltischen Trilobiten. Abt. VI. Ibid. St. Petersbourg.

Segerberg, 1906 See Moberg 1906.

Størmer, L., 1937: Planctonic Crustaceans from the Lower Didymograptus shale (3 b) of Oslo. Norsk geol. tidsskr. Bd. 16, pp. 267—278.

— 1938: To the problem of black graptolite shales. Ibid. bd. 17, pp. 173—176.

— 1940: Early description of Norwegian trilobites. Ibid. Bd. 20, pp. 113—151.

— 1945: Remarks to the Tretaspis (Trinucleus) Shales of Hadeland. Ibid. Bd. 25, pp. 379—426.

Strand, T., 1929: The Cambrian beds of the Mjøsen District in Norway. Norsk geol. tidsskr. Bd. X, h. 3—4.

Strøm, K., 1936: Land-locked waters. Hydrography and bottom deposits in badly ventilated. Norwegian fjords with remarks upon sedimentation under anaërobic conditions. K. norske Vidensk. Selsk. Oslo. Forh. I, no. 7.

Thorslund, P., 1935: Stratigrafiska och tektoniska studier inom Föllingeområdet i Jämtland. Sveriges geol. undersökning. Ser. C, no. 388.

— 1937: Notes on the Lower Ordovician of Falbygden. Geol. Inst. Uppsala Bull., vol. 27.

— 1938: Deep boring through the Cambro-silurian at File Haidar, Gotland. Sveriges geol. undersökning. Ser. C, no. 415.

— 1940: On the Chasmops Series of Jämtland and Södermanland (Tväran). Ibid. no. 436. (Årsbok 34, no. 6.)

— 1943: Gränsen Ordovicium-Silur inom Storsjöområdet i Jämtland. Ibid. Ser. C. no. 455.

Törnquist, S. L., 1884: Siljanområdets trilobitfauna. Ibid. no. 66.

— 1913: Några anmärkningar om indelningar inom Sveriges Kambrosilur.. Geol. fören. Stockholm Förh. Bd. 37, h. 7.

Vogt, Th., 1924: Om forholdet mellom Sparagmitsystemet og det marine underkambrium ved Mjøsen. Norsk geol. tidsskr. Bd. 7, p. 281.

— 1929: Den norske fjellkjedes revolusjonshistorie. Ibid. Bd. 10, p. 97.

Warburg, E., 1925: The trilobites of the Leptaena limestone in Dalarne. Geol. Inst. Uppsala Bull., vol. 17.

Westergård, A. H., 1928: Beskrivning till kartbladet Skövde. Sveriges geol. undersökning. Ser. Aa. no. 121.

Westergård, A. H., 1939: On Swedish Cambrian Asaphidae. Ibid., No. 421.

— 1940: Nya Djupborrningar genom äldsta Ordovicium och Kambrium i Östergötland och Närke. Ibid., no. 437.

Whittington, H. B., 1950: Sixteen Ordovician genotype trilobites. Jour. Paleontologø. Vol. 24, no. 5.

Wiman, C., 1905: Ein Shumardiaschiefer bei Lanna in Nerike. (Arkiv för Zoologi. K. svenska vetensk. akad. handl., Bd. 2, no. 11.

— 1906: Paläontologische Notizen, no 10. Über Holometopus. Geol. Inst. Uppsala Bull., Vol. 7, pp. 293—294.

— 1906 a: Studien über das Nordbaltischen Silurgebiete, II. Ibid. Vol. 8. (1906—07) (pr. 1908).

PLATES

The photographs are not retouched. All specimens whitened.
Abbreviations: P. M. O. = Paleontologisk Museum, Oslo.
R. S. = Naturhist. Riksmus. Palaeozool. Avd. Stockholm.

PLATE I

Figs. 1, 2, 5, 6, 11. *Megalaspis polyphemus* Brøgger.

Fig. 1. Free cheek. Lower Didymograptus Zone (3b) Heramb, Ringsaker. P. M. O. no. 66323. 0.6 ×. — Figs. 2, 5, 6. Holotype. (Brøgger 1882, pp. 74—75, figs. 2, 3.) Nearly complete specimen, enrolled. Horizon and locality unknown. P. M. O. no. 66398. 0.5 ×. — Fig. 11. The hindermost part of the pygidium. Lower Didymograptus Zone (3bδ) Heramb, Ringsaker. P. M. O. no. 66322. 1.1 ×.

Figs. 3, 7. *Megalaspis limbata* (Boeck).

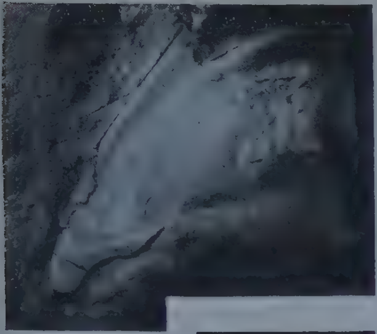
Fig. 3. Incomplete cranidium. Megalaspis Zone (3cα). Heramb, Ringsaker. P. M. O. no. 66330. 1 ×. — Fig. 7. Pygidium. Megalaspis Zone (3cα). Heramb, Ringsaker. P. M. O. no. 66325. 1 ×.

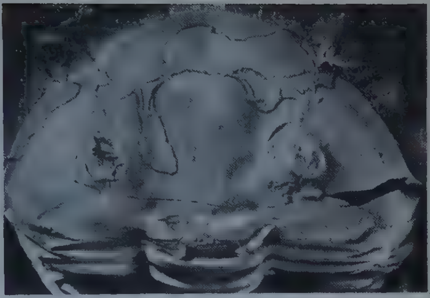
Figs. 4, 8. *Megalaspis heroides* Brøgger.

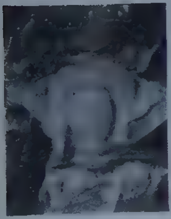
Fig. 4. Cranidium. Upper part of the Lower Didymograptus Zone (3b), Kårtveitbekken, Krekling (Brøgger coll.). P. M. O. no. 1538. 0.6 ×. — Fig. 8. Hindermost part of the pygidium. Upper part of the Lower Didymograptus Zone (3b), Kårtveitbekken, Krekling (Brøgger coll.). P. M. O. no. 1537. 1.8 ×.

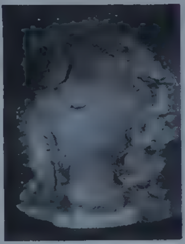
Figs. 9, 10. *Megalaspis planilimbata* Angelin.

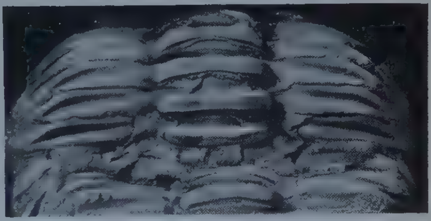
Fig. 9. Pygidium. (Brøgger 1882, pl. IV, fig. 7.) Upper part of the Lower Didymograptus Zone (3b), Krekling. P. M. O. no. H. 2633. 1 ×. — Fig. 10. Pygidium. Lower Didymograptus Zone (3b)? Ottestad, Stange. P. M. O. no. 61137. 1.1 ×.

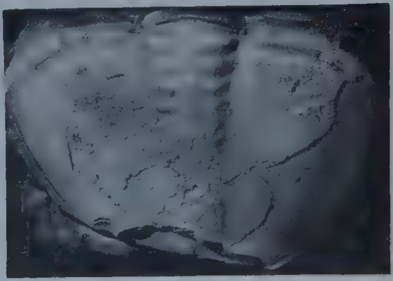

1

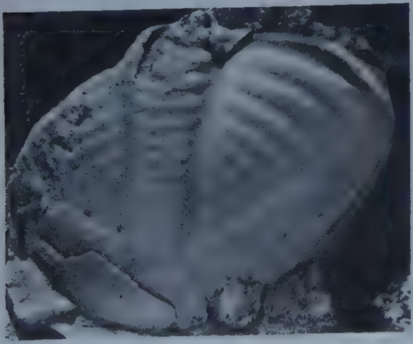

2

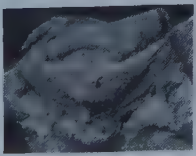

3

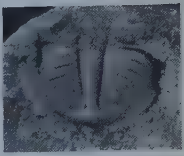

4

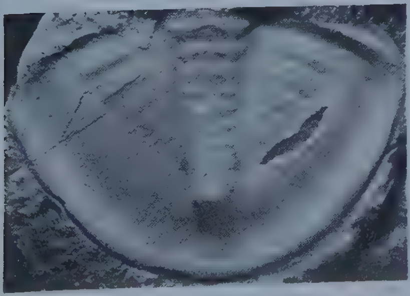

5


6


7


8


9


10

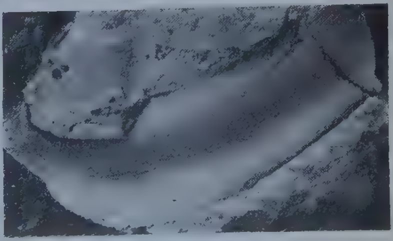

11

PLATE II

Figs. 1, 2, 3, 4, 6. *Megalaspis ringsakerensis* sp. n.

Fig. 1. Pygidium. Holotype. Lower Didymograptus Zone (3bγ), Heramb, Ringsaker. P. M. O. no. 66325. 1 ×. — Figs. 2, 3, 4. Incomplete pygidia. Lower Didymograptus Zone (3bδ), Heramb, Ringsaker. P. M. O. nos. 66326—28. 1.3, 0.9, 0.6 ×. — Fig. 6. Hypostome. Lower Didymograptus Zone (3b), Heramb, Ringsaker. P. M. O. no. 66324. 0.5 ×.

Figs. 5, 12, 13. *Niobe læviceps* Dalman.

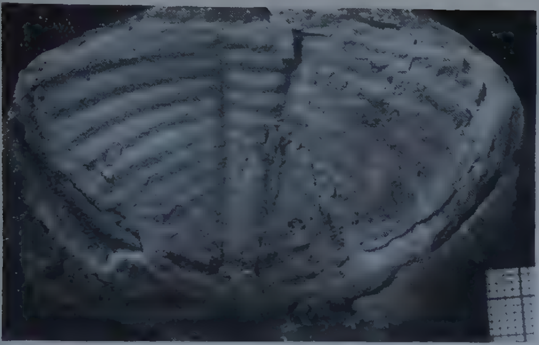
Fig. 5. Incomplete cranidium. Lower Didymograptus Zone (3bδ), Heramb, Ringsaker. P. M. O. no. 66315. 0.5 ×. — Fig. 12. Pygidium. Lower Didymograptus Zone (3bδ), Heramb, Ringsaker. P. M. O. no. 66301. 1.7 ×. — Fig. 13. Pygidium. Lower Didymograptus Zone (3bδ), Heramb, Ringsaker. P. M. O. no. 66314. 0.5 ×.

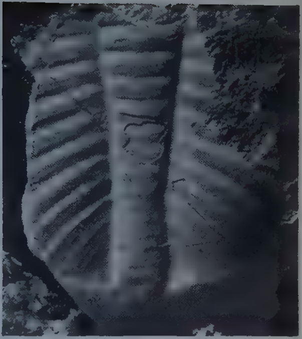
Figs. 7, 8, 11. *Nileus armadillo* Dalman.

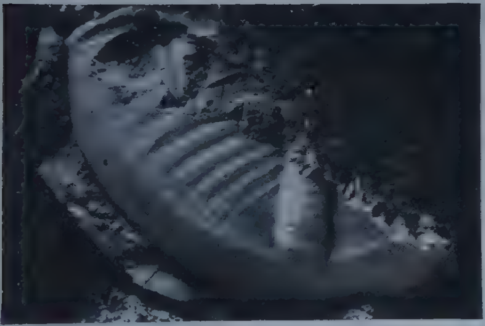
Fig. 7. Nearly complete, enrolled specimen. Lower Didymograptus Zone (3bγ), Heramb, Ringsaker. P. M. O. no. 66331. 1.5 ×. — Fig. 8. Cranidium. Lower Didymograptus Zone (3bδ), Heramb, Ringsaker. P. M. O. no. 66334. 1.4 ×.

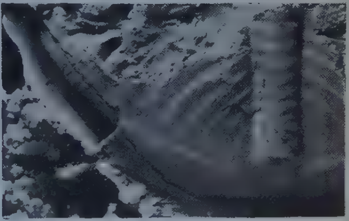
Figs. 9, 10. *Nileus limbatus* Brøgger.

Figs. 9, 10. Pygidia. Lower Didymograptus Zone (3b), Heramb, Ringsaker. P. M. O. 2.3 ×.

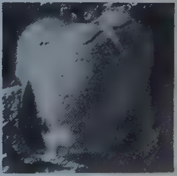

1

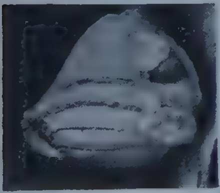

2

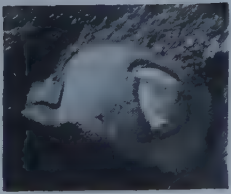

3

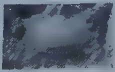

4

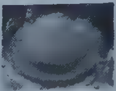
5

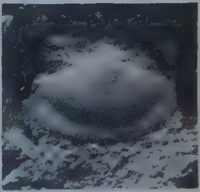

6

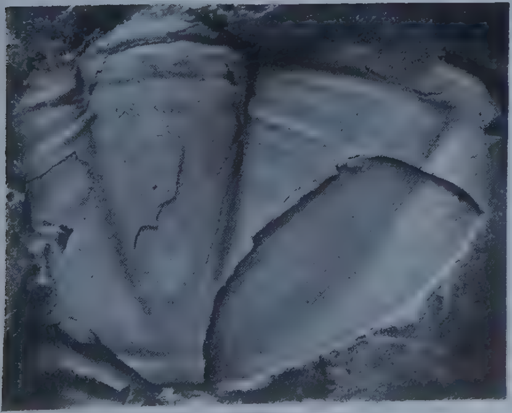

7


8


9


10


11


12

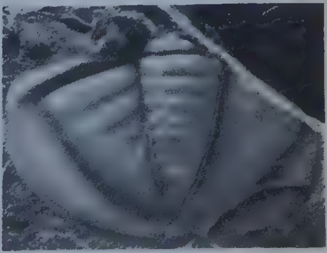
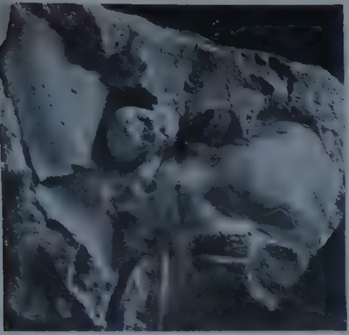

13

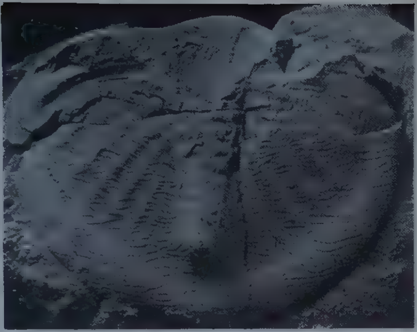
PLATE III

Figs. 1—8. *Ptychopyge herambensis* sp. n.

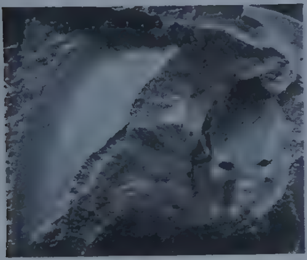
Fig. 1. Cranidium and free cheek. Lower Didymograptus Zone (3bγ), Heramb, Ringsaker. P. M. O. no. 66305. 1.2 ×. — Figs. 2, 3, 4. Holotype. Nearly complete enrolled specimen. — Fig. 2. Pygidium. P. M. O. nos. 66306—66307. 1.3 ×. — Fig. 3. External mould of hypostome. P. M. O. no. 66307. 1.3 ×. — Fig. 4. Hypostome (in situ). P. M. O. no. 66306. 1.3 ×. — Fig. 5. Pygidium. 3b, Heramb, Ringsaker. P. M. O. no. 66308. 1.2 ×. — Fig. 6. Pygidium. 3b, Heramb, Ringsaker. P. M. O. no. 66305. 1.2 ×. — Fig. 7. Pygidium (long variety), Heramb, Ringsaker. P. M. O. no. 66309. 1.2 ×. — Fig. 8. Pygidium and part of thorax. 3bδ, Heramb, Ringsaker. P. M. O. no. 66310. 0.9 ×.



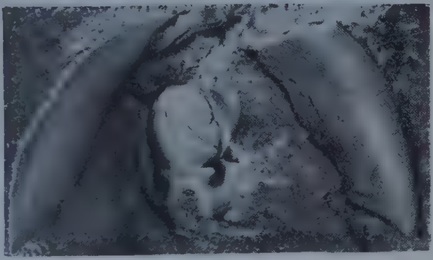
1



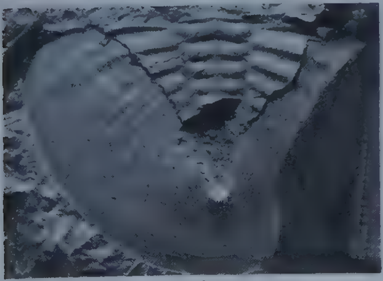
2



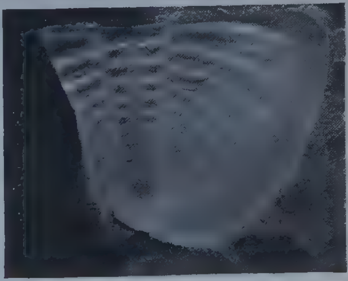
3



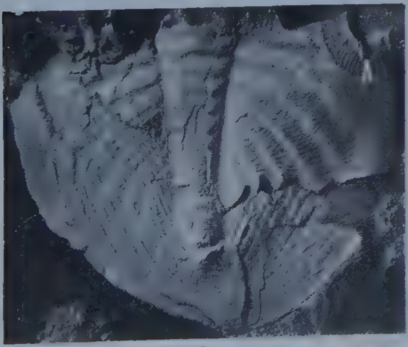
4

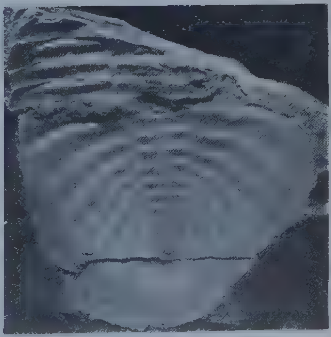


5



6





8

PLATE IV

Fig. 1. *Ptychopyge excavato-zonata* (Angelin) Holotype.
Pygidium. (Angelin, pl. 29, figs. 4, 4a) Öland. R. S. no. Ar. 22315. 2.3 ×.

Figs. 2, 5, 8, 9. *Ptychopyge minor* sp. n. Lower Didymograptus Zone (3bγ), Heramb, Ringsaker.

Fig. 2. Pygidium and part of the thorax. Holotype. P. M. O. no. 66311. 2 ×. — Fig. 5. Pygidium. 3bγ. P. M. O. no. 66312. 2 ×. — Fig. 8. Cranidium. 3bγ. P. M. O. no. 66314. 3.5 ×. — Fig. 9. Pygidium. 3bγ. P. M. O. no. 66313. 1.8 ×.

Fig. 7. *Ptychopyge* sp. Upper part of the Lower Didymograptus Zone (3b), Krekling. Brøgger coll. P. M. O. no. 1537. 1.5 ×.

Figs. 3, 4, 6. *Cyrtometopus clavifrons* (Dalman). Lower Didymograptus Zone (3bδ), Heramb, Ringsaker.

Fig. 3. Incomplete cranidium. 3bδ. P. M. O. no. 66338. 2 ×. — Fig. 4. Fixed cheek. 3bδ. P. M. O. no. 66340. 2 ×. — Fig. 6. Incomplete pygidium. 3bδ. P. M. O. no. 66340. 2 ×.

Figs. 10, 11, 14, 15. *Ceratopyge forficula* (Sars).

Fig. 10. Incomplete cranidium. Lower part of the Lower Didymograptus Zone (3bα), Sten, Ringsaker. P. M. O. no. 36056a. 4 ×. — Fig. 11. Hypostome. Horizon and locality as preceding. P. M. O. no. 36056b. 3 ×. — Fig. 14. Hypostome. Ceratopyge Limestone (3aγ), Slemmestad. P. M. O. no. 1402. 2 ×. — Fig. 15. Hypostome. Lower part of the Lower Didymograptus Zone (3bα), Sten, Ringsaker. P. M. O. no. 36056. 2 ×.

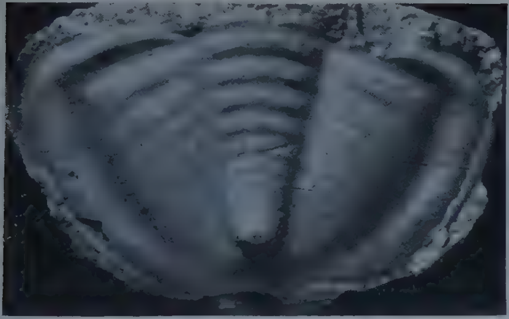
Fig. 12. Pygidium of trilobite. Lower Didymograptus Zone (3bγ), Heramb, Ringsaker. P. M. O. no. 36337. 2 ×.

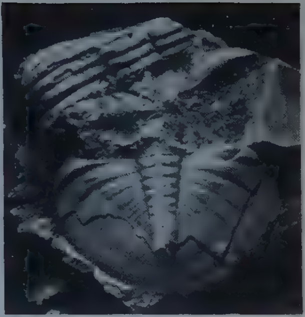
Fig. 13. *Symphysurus* sp. Lower Didymograptus Zone (3bγ), Heramb, Ringsaker. P. M. O. no. 66333. 1.6 ×.

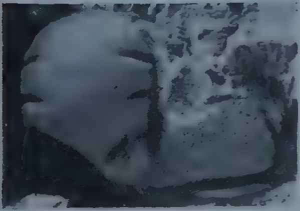
Figs. 16, 17, 19, 20, 21. *Raymondaspis limbatus* (Angelin). Lower Didymograptus Zone (3bγ-δ), Heramb, Ringsaker.

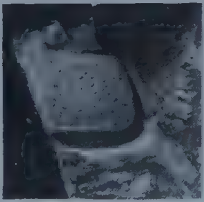
Fig. 16. Anterior view of pygidium. 3bδ. P. M. O. no. 66304. 3 ×. — Fig. 17. Pygidium. 3bδ. P. M. O. no. 66303. 2 ×. — Fig. 19. External mould of cranidium. 3bγ. P. M. O. no. 66302. 3 ×. — Fig. 20. Cranidium. 3bγ. P. M. O. no. 66302. 2 ×. — Fig. 21. Pygidium. 3bδ. P. M. O. no. 66301. 2 ×.

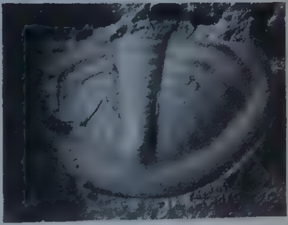
Fig. 18. *Trinodus* aff. *glabratus* (Angelin). Pygidium. Lower Didymograptus Zone (3bδ), Heramb, Ringsaker. P. M. O. no. 66301. 2 ×.

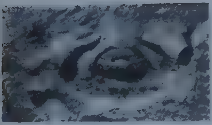

1

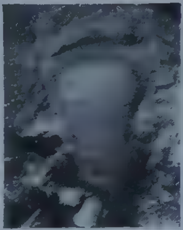

2

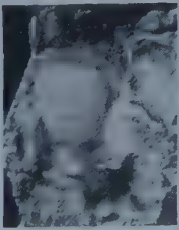

3

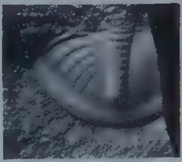

4

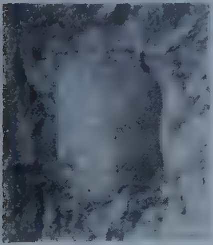

5


6


7

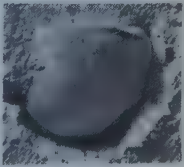

8


9

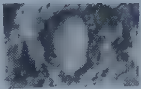

10

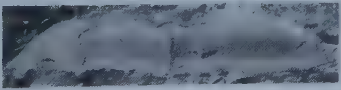
11

12


13

14

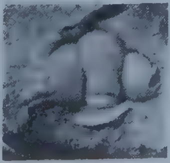

15


16

17

18

19


20

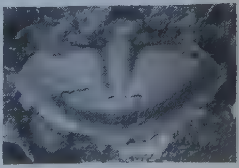

21

PLATE V

Figs. 1, 3, 5, 8, 9, 11. *Lonchodomas volborthi* (Schmidt). Lower Didymograptus Zone (3bγ-δ), Heramb, Ringsaker.

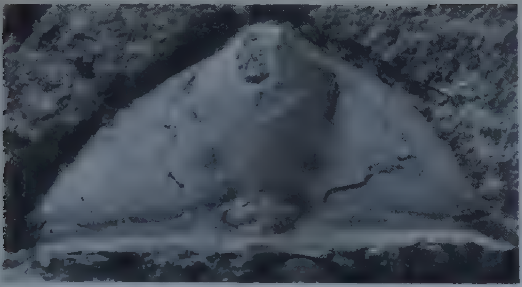
Fig. 1. Cranidium. P. M. O. no. 66319. 2 ×. — Fig. 3. Pygidium. 3bγ. P. M. O. no. 66320. 2.2 ×. — Fig. 5. Pygidium. 3bγ. P. M. O. no. 66320. 2 ×. — Fig. 8. Pygidium. 3bγ. P. M. O. no. 66318. 4 ×. — Fig. 9. Pygidium. 3bγ. P. M. O. no. 60318. 5 ×. — Fig. 11. Pygidium. 3bγ. P. M. O. no. 66317. 4.5 ×.

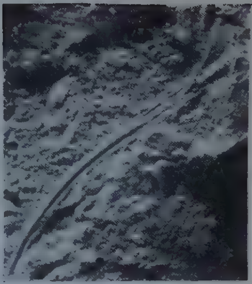
Figs. 4a, 6, 10. *Remopleurides* aff. *nanus* V. Leucht. Lower Didymograptus Zone (3bγ-δ), Heramb, Ringsaker.

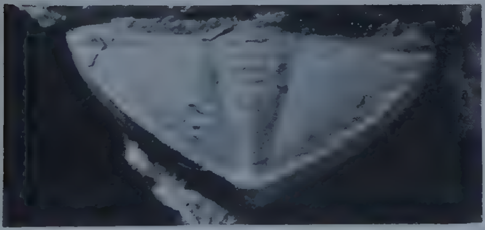
Fig. 4a. Cranidium. 3b. P. M. O. no. 66321. 3.3 ×. — Fig. 6. Cranidium. 3b. P. M. O. no. 66341. 3 ×. — Fig. 10. Larval cranidium. 3b. P. M. O. no. 66342. 20 ×.

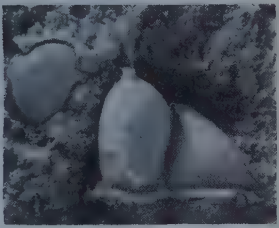
Figs. 2, 4b, 12—16. *Ampyx pater* Holm.

Fig. 2. Free cheek. Lower Didymograptus Zone (3bγ), Heramb, Ringsaker. P. M. O. no. 66343. 2.2 ×. — Fig. 4b. Side view of cranidium. Lower Didymograptus Zone (3bγ), Heramb, Ringsaker. P. M. O. no. 66321. 3.3 ×. — Fig. 7. Side view of cranidium. Lower Didymograptus Zone (3bγ), Heramb, Ringsaker. P. M. O. no. 66321. — Fig. 12. Cranidium. Lower Didymograptus Zone (3bγ), Heramb, Ringsaker. — Fig. 13. Cranidium. Lower Didymograptus Zone (3bγ), Heramb, Ringsaker. — Fig. 14. Cranidium. Skattungbyn, Dalarne, Sweden (type locality) Holm coll. Lower Didymograptus Shale. R. S. no. A_2 9254. — Fig. 15. Cranidium. Lectotype (chosen here). Lower Didymograptus Shale. Skattungbyn, Dalarne, Sweden. R. S. no. A_2 9254. (Holm, 1882, pl. figs 13—14). — Fig. 16. Cranidium. Lower Didymograptus Shale. Skattungbyn, Dalarne, weden. R. S. no. A_2 9256.

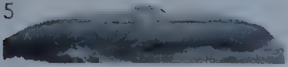

1

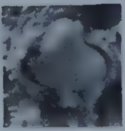

2

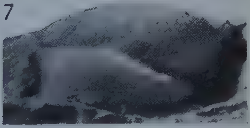

3


4 a

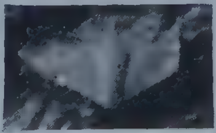
4 b


5

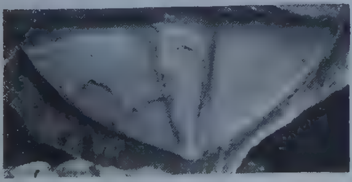

6

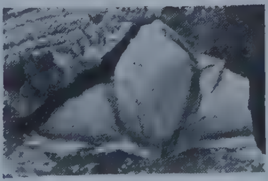

7

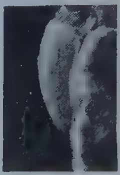
8

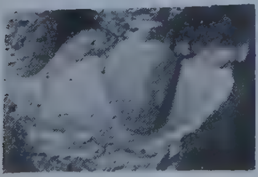

9

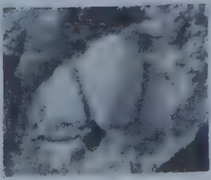
10

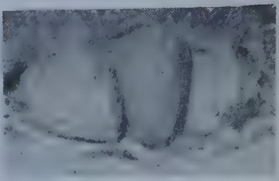

11


12


13


14


15


16

NARRATIVE OF A ROCK FRAGMENT

BY

OLAF ANTON BROCH

Apart from morainic drift and paleozoic sediments — the latter ones resting on the sub-cambrian peneplain more than a thousand meters above sea-level — all the rocks in Hol (Hallingdal, Norway) are of pre-cambrian age. The youngest among them is the Hol granite, which cuts the "bottom gneiss", a migmatite consisting of different gneissic, gneiss-granitic and granitic components. It also cuts the so called dagaligneiss, which is a porphyritic or perhaps augengneissic rock, resting more or less conformably on the migmatite. The dagaligneiss is the oldest of the Telemark supracrustals in this region.

In Djupedal (Hol), near the contact, the dagaligneiss is cut by numerous small dikes from the Hol granite. The dikes are quite regular ones with the common platy shape, and with thickness ranging from some few centimeters to about a meter. The dike rock has a sugar-grained structure — one might call it an aplite-granite — with no visible trace whatever of flowing. In addition, it is uniform throughout its whole mass, showing no border-facies.

The whole system nevertheless yields a proof of the existence of a flowing magma and therefore, particularly at this time, deserves notice.

The illustration (fig. 1) shows on its left side the dagaligneiss (dark) next to the light granite (right part of the specimen). The division in this case runs along the schistosity of the dagaligneiss. One may see a thin flake of dagaligneiss projecting obliquely into the granite. The flake has obviously become detached from the wall of dagaligneiss and just started on its way following the streaming magma, when the congealing of the last remaining liquid put a stop to the movement of this pulpy, viscous mass. The flake fits flush with the wall of the dagaligneiss, so that there can be little doubt as to its

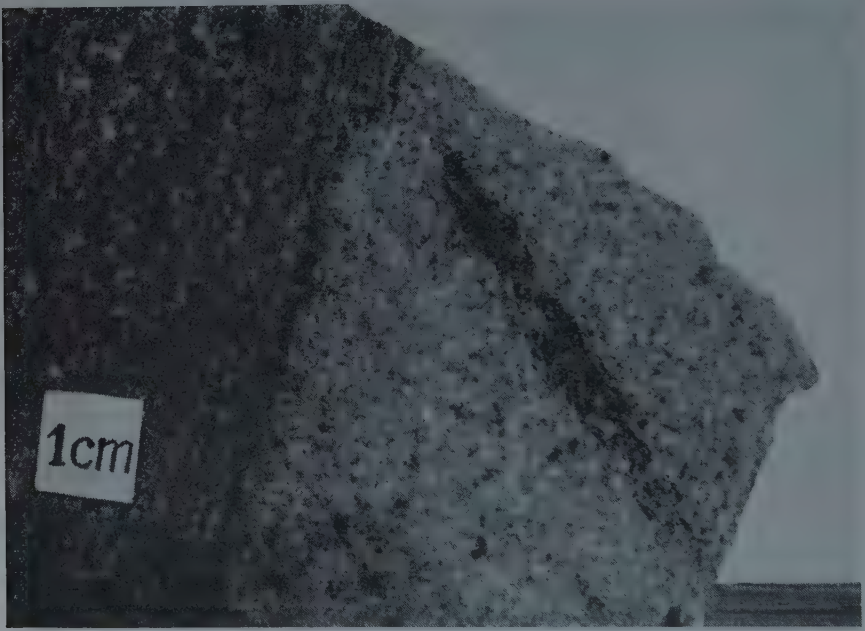


Fig. 1. Per Holmsen phot.

origin. It is by the way also obvious that the temperature was rather low, as there is no sign of plasticity in the dagaligniss. The flake is just broken away from the wall; there has been no bending nor slow yielding.

It is true, that this is only just another example of an igneous breccia. The distinctive feature of this occurrence is that the fragment has moved such a little distance from its place of origin, that this latter can be identified. According to the natural order of things, it is very seldom possible to make observations like the one described above.

NOTE ON A FAULT BRECCIA IN HALLINGDAL, NORWAY, TOGETHER WITH SOME GENERAL REMARKS ON THE FRACTURING OF THE EARTH'S CRUST

BY

OLAF ANTON BROCH

Some twenty years ago the author discovered a quartz breccia at Haga seter (chalet) in the pre-cambrian area south of Ål, Hallingdal. Air photographs (figs. 1 and 2) taken some time later revealed that the breccia belongs to a marked fracture line running SSW—NNE, parallel to the upper part of the valley of Hallingdal (maps figs. 3 and 4). This was soon afterwards confirmed by Ivan Th. Rosenqvist, who at the author's request undertook a geological survey (mapping) of the surrounding area. He was able to demonstrate that the fracture was filled throughout its entire length with quartz breccia, and that it represented a post-caledonian fault: The sub-cambrian peneplain — with folded paleozoic sediments resting upon it — north of the breccia is situated about 40 meters lower than it is to the south of it. The heights of the peneplain north and south of the breccia — 1070 and 1110 m. a. s. respectively — are recorded in the centre of the map fig. 3. (In the north-eastern part of this map one may see the large, post-caledonian explosion breccia (G) of Gardnos, cf. Broch l.c.)

In 1950 another breccia, similar to the one mentioned above, was discovered in the south-western extension of the line of direction taken by the upper part of the valley of Hallingdal, SW of the lake Strandefjord (western part of the map fig. 3). Just as in the case of the first-named breccia, this one also seems to dwindle in the south-west, whereas in the north-east it disappears under the thick valley-side moraine.

Like most other valleys of south-eastern Norway, Hallingdal in the greater part of its length runs SSE. The upper part, however, runs towards ENE. This somewhat puzzling feature seems to be explained by the existence of the breccias.

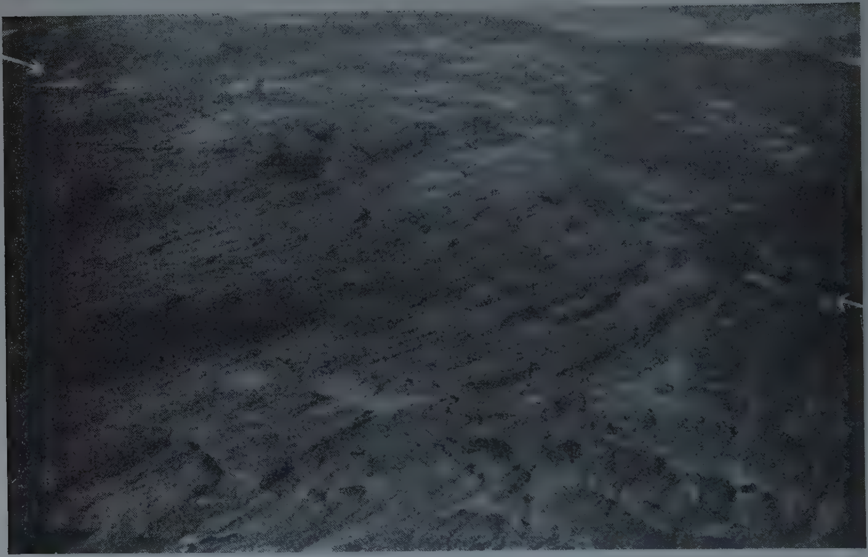


Fig. 1. Air-photo of the breccia from SE. In the background to the right, the valley of Hallingdal. Norsk Luftfoto A/S.

A glance at a good map of southern Norway reveals that many side-valleys, and also many fjords have the same direction as have the breccias mentioned, and a somewhat closer study will show, that this direction is a prominent feature in both major and minor topography. It is unquestionably a direction of fractures, and in some cases also a direction of traceable faults, e. g. the fault referred to above, the horst of Mjøsa (H on fig. 4) and part of the great breccia (Br) in the pre-cambrian of southern Norway (Bugge l. c.). Without necessarily implying any hypothesis by this, we may call it the Skager Rack direction. We shall not, however, go into further details, especially in view of the fact that a broader treatment of the fractures of southern Norway is in preparation elsewhere.

A striking feature of the fractures of the Skager Rack direction is that their formation extends over a very lang period of time. As an example we shall look at the great pegmatite dikes and some of the fracture lines in eastern Østfold (P on fig. 4). The dikes belong to the pre-cambrian Bohuslän-Østfold granite, and will be dealt with in somewhat greater detail in a paper under preparation. They are true

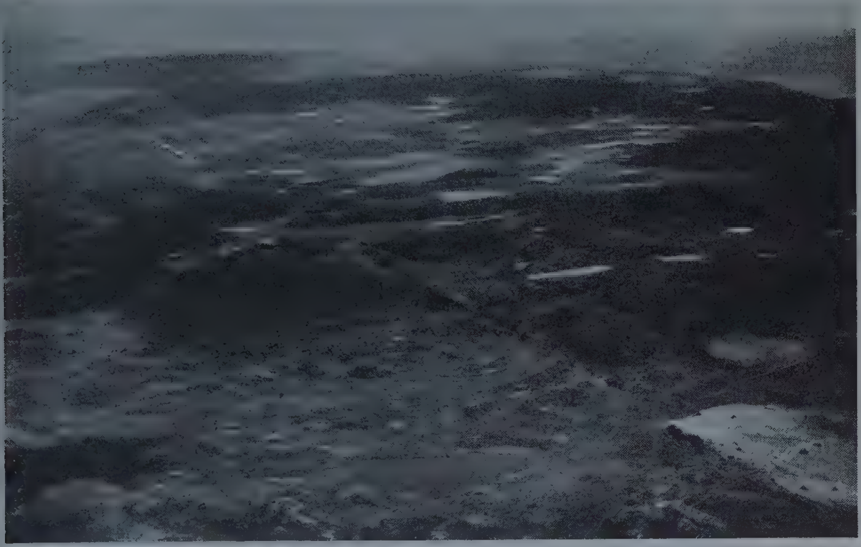


Fig. 2. Air-photo from NW. Lower right corner: The breccia at Haga seter. Norsk Luftfoto A/S.

fracture dikes, running ENE—WSW. Those fractures were obviously formed and also sealed up with pegmatitic solutions in pre-cambrian time. In the same region we have, however, much younger, open fractures of the same direction. They are seen in the field, and having, unlike the old, sealed up fractures left their mark on the landscape, they are well revealed by detailed topographic maps. — Another example is given by the great southern brecia (Br). From Bugge's description (l. c.) it appears that there have been repeated movements. — Yet another, very striking example is provided by the horst of Mjøsa (H). According to Skjeseth (l. c.) the movements along the faults started in eo-cambrian and continued up to permian time, perhaps even much longer, as there are, apart from the quaternary deposits, no younger rocks than permian there.

The examples selected above give an illustration of a rule which is no doubt recognized by geologists in many parts of the world. We may call it the rule of the *tendency within a given region towards constancy over geologic periods of the directions of fracturing of the Earth's crust.*

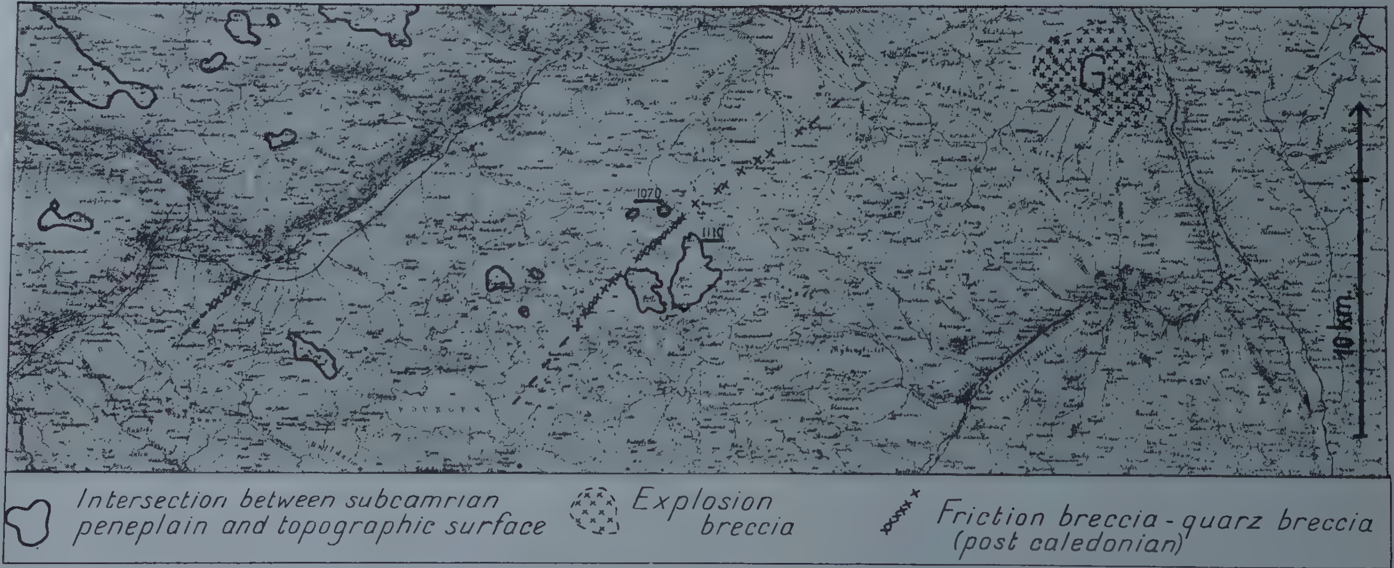

G
10 km.
1070
1110
Intersection between subcamrian peneplain and topographic surface
Explosion breccia
Friction breccia - quarz breccia (post caledonian)

Fig. 3. Map of the breccia with major geological features of the surrounding area. Topography after Norges geografiske Opmåling, gradavd. E33. Use a magnifying glass.

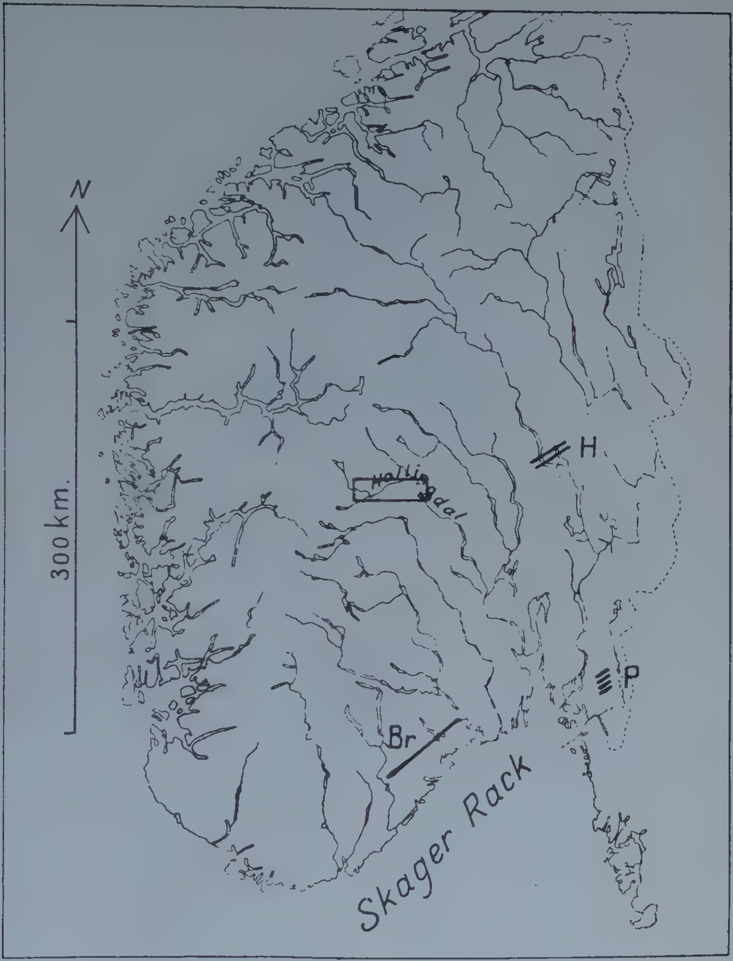


Fig. 4. Map of southern Norway. Key to fig. 3 etc.

References.

1. Broch, Olaf Anton: Gardnosbreksjen i Hallingdal. Norsk geol. tidsskr. 25, p. 16—25. Oslo 1945
2. Bugge, Arne: En forkastning i det syd-norske grunnfjell. Norges geol. unders. 130. Oslo 1928.
3. Skjeseth, Steinar: Verbal communication.

STATSGEOLOG STEINAR FOSLIE

Minnetale holdt 14. februar 1952.

AV CARL BUGGE

Det var et uventet budskap som kom at Statsgeolog Foslie døde mandag 19. november 1951. Som vanlig i sommerhalvåret hadde han også sommeren 1951 vært i full virksomhet ute i marken med geologisk kartlegging og geologiske studier. Han var kommet tilbake om høsten fra Nissedal hvor han har arbeidet i flere år, og var i full gang med bearbeidelse av sitt materiale, da han døde helt plutselig. Det er et stort tap for norsk geologi.

Foslie var en fremragende vitenskapsmann. Han var kjent blant geologene i alle land ved sine mange publikasjoner, hvor man alltid fant noe nytt og interessant.

Foslie hadde omfattende kunnskaper i de forskjelligste grener av mineralogien og geologien. Det var først og fremst i malmgeologi og petrologi han hadde spesialisert seg. Han hadde reist meget omkring i vårt land og var også vel kjent med de viktigste malmfelter i flere andre land, særlig i Sverige og Mellomeuropa.

Foslie var født i Tromsø 1887. Hans far, Mikael Heggelund Foslie, var konservator ved Tromsø Museum, fra 1893 ved Det kongelige norske Videnskabers Selskabs museum i Trondheim.

Steinar Foslie ble student 1905, cand. min. (bergkandidat) ved Universitetet i Oslo 1909 og ble samme år ansatt ved Norges geologiske undersøkelse. Han fikk sin eksamen med innstilling til kongen.

Ved N. G. U. virket han hele sin tid, altså i 42 år. Hver eneste sommer var Foslie ute i marken på geologisk kartlegging og geologiske studier. Allerede i studietiden hadde han foretatt reiser i Møre—Romsdal og Sogn og Fjordane fylker, som assistent for professor J. H. L. Vogt som den gang holdt på med å samle materiale til sin bok: Norges jernmalmforekomster, N. G. U. nr. 51. Foslies oppdrag var undersøkelse av de titanholdige jernmalmforekomster.

Dette arbeide med undersøkelse av Norges forråd av jernmalm ble utført for den Internasjonale Geologkongress i Stockholm 1910, som hadde jordens tilganger på jernmalm som hovedtema. I den forbindelse bemerkes, at jernmalmene også skal behandles på den internasjonale geologkongress som i år holdes i Algier. N. G. U. har sendt et bidrag ved statsgeolog Poulsen til kongressens publikasjoner.

Foslie fortsatte sine undersøkelser over titanholdige jernmalmer og publiserte 1913 en avhandling om Ramsøy titanjernmalm i Solør og dets differentiasjonsprosesser (N. G. U. nr. 68).[1] I 1928 hadde han en avhandling om »Gleichgewichtsverhältnisse bei einigen Titaneisenerzen«, Fennia, Helsinki.

I årene 1912—13 foretok Foslie med stipendium fra Bergfondet en lang studiereise til noen av de største bergverkene i Sverige, Tyskland, Ungarn, Østerrike og Lilleasia. Hans innberetning ble funnet så grundig og interessant at Departementet foranlediget arbeidet trykt. Det utkom på Aschehougs forlag, Oslo, i 1920 og er på 379 sider, med mange karter og figurer. Titelen er: Gruber og Grubedrift. Der er geologiske og bergmessige beskrivelser fra en mengde grubedistrikter. Man kan her lese om Kirunavara, Gellivara, Mansfeld, Clausthal, Rammelsberg, Minnettemalmene og meget annet.

Under hele sin virksomhet samlet Foslie opplysninger om gruver og skjerp i Norge. Hos bergmestrene i Sydnorge fikk han anledning til å gjennomgå bergarkivene og på grunnlag herav utarbeidet han et kart i 1 : 1 million over beliggenheten av malmforekomster i Sydnorge. Det ble trykt med beskrivelse i 1925 (N. G. U. nr. 126) og har titelen Syd-Norges gruber og malmforekomster. Det er en meget nyttig bok for berginteresserte.

Til den XIV Internasjonale Geologkongress i Spania 1926 utarbeidet Foslie en oversikt over Norges Svovelkisforekomster som et bidrag til et arbeid over verdens forråd av svovelkis, som ble utgitt av kongressen. Foslies arbeide ble i noe utvidet form også utgitt av Norges geologiske undersøkelse (N. G. U. nr. 127).

---

[1] Fortegnelse over Foslies publikasjoner, utarbeidet av R. Falck-Muus, følger etter denne artikkel

Foslie deltok også i den XVI Internasjonale Geologkongress i Toronto, 1933. Kongressen utga en publikasjon om »Copper resources of the World«. Til denne leverte Foslie en oversikt over »Copper deposits in Norway«. Om dette skrev han samme år i Naturen, Bergen.

I mange år arbeidet Foslie i Ofotendistriktet. Hans arbeidsfelt var området syd for Ofotenfjorden. Om sine kartlegginger og undersøkelser i dette felt har han utgitt følgende publikasjoner:

Raana Noritfelt, N. G. U. nr. 87, årbok 1920 21.
Tysfjords Geologi, N. G. U. nr. 149, år 1941.
Hellemobotn og Linnajavre, N. G. U. nr. 150, år 1942.
Melkedalen gruber i Ofoten, N. G. U. nr. 169, år 1946.
Håfjellsmulden i Ofoten og dens sedimentære jernmanganmalmer, N. G. U. nr. 174, år 1949.
»On antigorite-serpentines from Ofoten with fibrous and columnar vein minerals«, i Norsk geol. tidsskr. bd. 12, år 1931.
»Hastingsites and amphibolites from the epidote-amphibolite facies«, i Norsk geol. tidsskr. bd. 25, år 1945.

Foslie har således gått meget grundig fram i sine studier over Ofotenfeltet. Han hadde ennå igjen et oversiktsarbeide over hele området med alle de kjemiske analyser som han hadde fått utført. Dessuten hadde han ferdig manuskript gradteig Ofotens sydlige del.

Foslies geologiske karter er alltid meget nøyaktige og fullstendige. De stratigrafiske og tektoniske forhold er utmerkete. Han gir også i sine publikasjoner fremragende petrologiske beskrivelser av bergartene. Malmer og nyttige bergarter er beskrevet på beste måte.

På kartene har han angitt gode ledenivåer. I »Raana noritfelt« viser han en interessant differentiasjonsserie og de 2 avhandlingene om serpentinmineraler og hornblender er også meget betydningsfulle. Av særlig aktuell interesse er hans bok om manganmalmene. En sammenfatning om Mangansilikat-malmer i Ofoten har han gitt i Tidsskr. for Kjemi, bergvesen og metallurgi, p. 160, år 1948.

I begynnelsen av 1920-årene var Foslie i det vesentlige ferdig med markarbeidene i Ofoten og han tok så fatt på Grongfeltet.

I årbøkene N. G. U. nr. 96, 122 og 133 har han omtalt kartleggingen her inntil 1928. Han fortsatte til slutten av 1930-årene og det foreligger nå et ferdig manuskriptkart over Grongfeltet omfattende en serie rektangelkarter, hvorav de som ligger sentralt i Grongfeltet er kartlagt i sin helhet, mens grensebladene er kartlagt delvis av hensyn til arronderingen av feltet. Kartleggingen er som vanlig foretatt i målestokk 1 : 50 000. Det kan bli tale om å utgi kart over Grongfeltet i denne skala eller i 1 : 100 000, eventuelt også i 1 : 250 000. Det foreligger detaljerte dagbøker og representative samlinger av bergarter og malmer. Visstnok også en serie kjemiske analyser. Dessverre har Foslie ikke fått ferdig noen geologisk beskrivelse av feltet.

På foranledning av Bergverkskontoret i Industridepartementet utarbeidet han i 1949 en bergmessig uttalelse om malmbeholdningen i Grongfeltet, hvorav et utdrag er trykt i Tidsskrift for Kjemi, bergverksdrift og metallurgi 1949, p. 177.

I Grongfelteet er der en nikkelforekomst noe avsondret fra de store kisforekomster. En beskrivelse av denne forekomsten er utgitt 1932 av Foslie og Mimi Johnson Høst i N. G. U. nr. 137: Platina i sulfidisk nikkelmalm.

Som nevnt vil det sikkert være mulig å utgi Foslies karter. Forhåpentlig lar det seg også gjøre å utnytte det øvrige materiale, så det kan bli utgitt en publikasjon om resultatene av undersøkelsene i Grongfeltet.

Etter at Foslie var ferdig med markarbeidet i Grong fikk han i begynnelsen av 1940-årene 2 nye arbeidsfelter, nemlig gradteig Nisser og malmfeltet Varaldsøy—Ølve i Hardanger. Nissedal hadde en særlig interesse på grunn av Søftestads jerngruver. Foslie regnet nå å være ferdig med markarbeidet på denne gradteig.

Feltet i Hardanger var han også ferdig med. Han hadde utarbeidet flere karter som for tiden er under trykning. Beskrivelsen foreligger også ferdig, så man kan vente en publikasjon om dette felt.

Det er således 4 store arbeidsfelter Foslie arbeidet med. Forøvrig har han reist meget rundt i landet. Av iakttagelser han har beskrevet kan nevnes »Cyanit i den ytre gangsone av granit«, Norsk geol. tidsskr. bd. 2, 1912.

Om asbest skrev han i tidsskr. for. bergvesen nr. 5, 1917.

I Journal of Geology, 1921, bd. 29 skrev han om »Field observations in Northern Norway, bearing on magmatic differentiation.«

Videre nevnes følgende avhandling som ble utarbeidet for Statens Råstoffkomité: Foslie og C. Bugge: Norsk Arsenmalm og arsenikfremstilling, N. G. U. nr. 106, 1932.

I sine kartbladsbeskrivelser hadde Foslie foruten geologisk beskrivelse av berggrunnen også meget gode utredninger av kvartærgeologien. I denne forbindelse kan nevnes hans publikasjon Brofoshølen i Tunhøvd. Norsk geol. Tidsskr. Bd. 5, 1920.

Da Foslie var i 30-årsalderen i 1917, altså under forrige verdenskrig, deltok han i en merkelig reise. Han deltok nemlig i den av professor Sederholm organiserte reise til Jenissei i Sibiria. Sjefen var Sederholm og øvrige deltagere H. Hausen, Backlund, Foslie og Brenner.

En publikasjon om reisen utkom i 1927 i Acta Geographica, bd. 1, hefte 1, tidsskriftet for Geografiska Sällskapet i Finnland. Publikasjonen ble forfattet av professor Hausen i samarbeid med deltagerne. Publikasjonens titel er »The Upper Jenissei drainage area, (territory of Uriankhai)«. Under reisene som han gjorde 4 måneder på hesteryggen, utarbeidet han flere geologiske kartskisser. Øvre Mongolia var et meget tiltalende land, skrev han.

Foslie var medlem av flere vitenskapelige og tekniske foreninger, således av Norsk geologisk forening, siden 1911, Norsk ingeniørforening, Det norske vitenskapsakademi i Oslo siden 1935 og Geogiska Föreningen i Stockholm siden 1926.

Ellers deltok han ikke i det offentlige liv.

Han var sensor i mineralogi og petrografi ved Universitetet i Oslo.

Foslie var meget benyttet av bergverkene og berginteresserte som ekspert ved undersøkelse av malmer og andre mineralske råstoffforekomster. Det er mange rundt om i landet som han har gitt hjelp og gode råd. Geologene og bergmennene minnes ham med takk.

I Geologische Rundschau bd. 39, H. 1, år 1951, skrev professor Wegmann i Neuchatel kort før Foslies død i meget anerkjennende ord en anmeldelse av hans publikasjoner i senere år.

Om Foslie skal jeg for øvrig si at vi kjente ham som en stillfarende, hyggelig og grei mann.

Det er nå ikke så mange tilbake av bergkandidatene fra Universitetet i Oslo. Det er jo omtrent 40 år siden studiet ble flyttet over til Trondheim. Vi som kom fra Universitetet sender Foslie en særlig tanke og vi samles alle og hedrer hans minne.

STEINAR FOSLIES YRKE I TRYKK OG SKRIFT

Bibliografiske opplysninger.

VED

ROLF FALCK-MUUS

Direktør dr. Carl Bugge har bedt ovennevnte være ham behjelpelig med å få i stand en bibliografi over statsgeolog Steinar Foslies arbeider, hvilket jeg mer enn gjerne har påtatt meg. Jeg takker dr. Bugge for oppdraget, likeledes »Norges geologiske undersøkelse«, som har satt meg i stand til å utføre det.

Nedenfor bringes da en — såvidt den korte tiden av under 2 uker tillater det — så fyldig som mulig fortegnelse over hva Steinar Foslie virket gjennom trykk og skrift.

Nærværende forfatter har dog ikke kunnet ta med enhver av de utallige saker, hvor Steinar Foslies mening, hans råd eller hans hjelp har vært utesket, selv om det til belysning av disse spørsmål også finnes et stort og velordnet arkiv. En har søkt å begrense seg til hva vår kjære avdøde venn har publisert i dagspressen og i den vitenskapelige faglitteraturen.

Til utdyping av stoffet er der til slutt tatt med de nekrologene, som til dags dato har sett dagens lys, liksom der kortelig nevnes hva Steinar Foslie har produsert, men som ennå ikke er publisert.

Spesielle publikasjoner.

A.-B. Mineralkompaniet. Helsingfors 1918. Reseberättelser från expeditionen till Uriankhai, år 1917.

s. 93—144: Rapport fra St. Foslie.[1]

---

[1] Det var neppe noe som irriterte Steinar Foslie mer enn når hans navn ble forkortet, så det kunne leses: Sankt Foslie.

Congres Géologique International.
XIV. Madrid 1927. s. 159—241: Pyrite Resources of Norway — som del av: »Les reserves mondiales en pyrite«.
XVI. Washington 1935. s. 605—614: Copper Deposits of Norway — som del av: »Copper Resources of the World«.

Gruber og grubedrift. I—V + 379 s. Med 18 karter og plancher og 101 figurer i teksten. Kr.a 1920 (Aschehoug & Co.). [Stipendieinnberetning til Bergfondet over reiser til gruber og verk i Nordsverige, Tyskland, Østerrike og Ungarn.]

Tidskrifter.

Teknisk Ukeblad.
(LVIII). 1911. s. 204—206: Om eventuell separation av nikkelholdig magnetkis.
(LXIV). 1917. s. 339—341: Litt om asbest, dens forekomst og anvendelse.
(LXVI). 1919. s. 456—458: Kulskiferen ved Gjøvik.

Norsk Geologisk Tidsskrift.
II. 1912. s. 26—29: Cyanit i den ytre gangzone av granit.
— — s. 37—41: Norsk Geologisk Forenings virksomhet i 1912 (1913).
III. 1913 hft. 10. s. 7—20: Norsk Geologisk Forenings virksomhet i 1913 (1914).
— — s. 65—84: Norsk Geologisk Forenings virksomhet i 1914 (1915).
— — s. 66: Disk.[2] etter hans foredrag: »Tyngdens betydning for malmes differentiation« (trykt i N. G. U. Nr 68: Ramsøy titanmalmfelt).
IV. 1915. s. 33: Disk. etter Holtedahls foredrag: »Noen foreløbige meddelelser fra en reise i Alten.«
— — s. 49: Disk. etter Reuschs foredrag »Litt om en kulholdig substans fra Hallingdal«.
— — s. 268: Disk. etter C. Bugges foredrag »Om Kongsberg«.
V. 1918. s. 298—299: Referat av foredrag: »Fra min reise til Mongoliet sommeren 1917.«

---

[2] Disk. brukes som forkortelse for diskusjonsinnlegg.

V 1919. s. 187—210: Brofoshølen i Tunhøvd.

— — s. 403—405: Disk. etter Goldschmidts foredrag »Om de mekaniske principer for skred og utrasninger«.

— — s. 414: Disk. etter eget foredrag om »Norges største jettegryte [Brofosshølen]«.

VI. 1920. s. 248: Disk. etter eget foredrag om »En ny type av differentiationsprosesser (Rånafeltet)«.

— — s. 257: Disk. etter Falkenbergs foredrag om »Norske Molybdænforekomster«.

— — s. 262: Disk. etter Goldschmidt foredrag om »Stavangerfeltet«.

— — s. 266: Tale ved avsløringen av dr. Reuschs malte billede i N. G. U. (på møtet i N. G. F.).

— — s. 270: Disk. etter Vogts foredrag »Om gasarter i magma etc.«.

— — s. 272: Disk. etter Bjørlykkes foredrag om »Undergrundsbanen«.

— — s. 275: Disk. etter Vogts foredrag »Om Nordkapplatåene«.

— — s. 283: Disk. etter Carstens foredrag »Av Trondhjems feltets geologi«.

— — s. 284: Disk. etter Bjørlykkes foredrag om »Nyere retninger innen aggrogeologien eller jordlæren«.

— — s. 286: Disk. etter Rekstads foredrag om »Grundvandet«.

VII. 1922. s. 72—74: Disk. etter Vogts foredrag om »Nordlandsfjellkjedens stratigrafi og tektonik.

— — s. 402: Disk. etter Vogts foredrag »Om diskonformitet mellem sparagmitsystemet og det marine kambrium«.

IX. 1927. s. 405: Foredrag i N. G. F. »Det sydspanske kisfeldt«. [Foredraget er hverken trykt eller referert.]

X. 1929. s. 460: Foredrag om »Likevektsforhold i titanmalmer« (trykt i Fennia, se der).

XI. 1931. s. 437—439: Johan H. L. Vogt 14. okt. 1858—3. jan. 1931 [!]. Noen minneord om professor Vogt.

— — s. 499: Minnetale holdt 1.3.1932 (Om Vogt).

XII. 1931. s. 219—245: On Antigorite-Serpentines from Lofoten with Fibrous and Columnar Vein Minerals.

13 (XIII). 1932. s. 321: Foredrag om »Platina i sulfidisk nikkelmalm« — se N. G. U. Nr 137.

14 (XIV). 1933. s. 201—209: Statsgeolog J. B. Rekstad. Nekrolog og bibliografi.

— — s. 325: Minneord over statsgeolog John B. Rekstad (på møtet i N. G. F. — se foregående).

— — s. 324: Foredrag om »Norges kobberforråd og dets fordeling på forekomstgrupper« (se: Copper Resources of the World).

17 (XVII). 1937. s. 214—216: Disk. etter foredrag av Vogt om noen »Betraktninger over kisforekomstenes dannelse«.

18 (XVIII). 1938. s. 75—77: Disk. etter foredrag av Barth og Holtedahl vedr. »Sparagmittens metamorfose i fjellkjedestrøkene«.

19 (XIX). 1939. s. 115—116: Skorovas kisfelt i Grong. Ref. av foredrag i N. G. F.

22 (XXII). 1942. s. 219: Disk. etter foredrag av Oftedal om »En norsk litiumpegmatitt«.

24 (XXIV). 1945. s. 257: Disk. etter foredrag av Gleditsch om »Leptit-begrepet«.

— — s. 261: Foredrag »Om hastingsiter og hornblende fra epidotamfibolitfacies«. (Se neste.)

25 (XXV). 1945. s. 74—98: On Hastingsites and Amphiboles from the Epidot-Amphibolite Facies.

28 (XXVIII). 1949. s. 144—150: Supergene Marcasite, replacing Pyrrhotite.

— — s. 258: Foredrag i N. G. F. om »Malmforrådene i Grongfeltet«. [Ikke referert.]

Tidsskrift for Bergvesen.

I (1913). s. 39—43, s. 63—69: Skakttaarne av træ, deres konstruktion og beregning.

III (1915). s. 129—133: Bergverket Rammelsberg og dets nyeste avbygningsmetode. (Avsluttes i neste.)

IV (1916). s. 25—30: Bergverket Rammelsberg etc.

V (1917). s. 53—57: Litt om asbest, dens forekomst og anvendelse.

VII (1919). s. 37—41: Kulskiferen ved Gjøvik.

— — s. 142—145: En norsk Haandbok for Berginteresserte, samt en større Norges Geologi. (Rapport fra komiteen nedsatt av Bergingeniørforeningen for å utrede samme spørsmål — forfattet av Steinar Foslie og publisert i redegjørelse for samme spørsmål av Rolf Falck-Muus.)

(Tidsskriftet fortsatt fra 1921 som Tidsskrift for Kjemi og Bergvesen. Se der.)

Norges Geologiske Undersøkelse.

(Skrifter Nr *68*. Aarbok for 1913. s. 1—76: Ramsøy titanjernmalmfelt. 7 karter.

— — *87*. Aarbok for 1920. s. 1—52: Raana noritfelt.

— — *98*. Aarbok for 1922. s. 27—42: Grongdistriktet. 1 planche.

— — *106*. (Statens råstoffkomites publ. no. 6.) (og Carl Bugge). 1922. s. 1—33: Norsk arsenmalm og arsenikkfremstilling.

— — *122*. Årbok for 1923. s. 59—70: Grongdistriktet.

— — — — — — s. 70—73: Vanntunnellen Tunhøvd-Nore.

— — — — — — s. 73—77: Utsjø-gruben ved Eidsvolls gullverk.

— — *126*. 1925. s. 1—89: Syd-Norges gruber og malmforekomster. Kart i 1 : 500 000 medfølger.

— — *127*. 1926. s. 1—122. Norges svovlkisforekomster.

— — *133*. 1929. s. 31—38: Beretning om arbeidet i 5-årsperioden 1924—28.

— — — 1929. s. 34—36: Björnådalens kleberstensbrudd i Vefsn.

— — *137*. 1932. s. 1—71 (og Mimi Johnson Høst): Platina i sulfidisk nikkelmalm.

— — *149*. 1941. s. 1—298: Tysfjords geologi. Geol. kart medfølger.

— — *150*. 1942. s. 1—119: Hellemobotn og Linnajavre. 2 geol. karter medfølger.

— — *169*. 1946. s. 1—108: Melkedalen grube i Ofoten. Søndre Ofoten Malmforekomster I. 16 plansjer og 2 karter.

— — *174*. 1949. s. 1—174: Håfjellmulden i Ofoten og dens sedimentære jern-mangan-malmer. Søndre Ofoten Malmforekomster II. 12 plansjer og 7 karter.

Journal of Geology (Chicago Ill.)

XXIX. 1921. s. 701—719: Field Observations in Northern Norway, bearing on Magmatic Differentiation.

Acta Geographica (Helsingfors).

I. 1927. s. 1—186: H. Hausen. The Upper Yenissei Drainage Area (Territory of Uriankhai). Her har Steinar Foslie skrevet følgende avsnitt: s. 126—132: Route n:o 1 — : Hlebnikova-Ust Bilbei — Ust Sidzim — Sidzim (upstream) — Dshivei (downstream) — Huakhem — Ust Ushep — Ushep (upstream)

— Karasuk — Idyk mountain — Karadsharyk — Shuy — Huakhem — Hlebnikova.
s. 132—136: The Devonian Terrane [!] at Hlebnikova (Huakhem). (With a geological Map.)
s. 157—164: Route n:o 2: Hlebnikova — Uluk Dshivei — Haptagai — Khargin gol — Terinur (Terkul) — Kuria — upper course of Khargin gol — Kha-gol — Bokhur — northern crest of Tangnu-Ula the same way back to Hlebnikova.
s. 164—69: The Geological Outlines of the Huakhem Drainage Area from Hlebnikova in the west of the Terinur (-kul) lake in the east.

Tidsskrift for Kjemi og Bergvesen (før 1921 se: T. f. Bergvæsen).
VIII (XVI). 1928. s. 30—32; s. 48—51: Verdens svovlikisforråd.
XI (XIX). 1931. s. 90: Bjørn Tiberg: Mineralfyndigheter. Anmeldelse.
XVII (XXV). 1937. s. 5: Diskusjonsinnlegg etter Kjell Lunds foredrag om »Kismalmers flotasjonsmuligheter« (Bergmannstinget 14.10.1936).
(Tidsskriftet fortsatt fra 1941 som Tidsskrift for Kjemi, Bergvesen og Metallurgi — se der.)

FENNIA (Helsingfors).
L.nr 26. 1928. s. 1—16: Gleichgewichtsverhältnisse bei einigen Titaneisenerzen.

Tidsskrift for Kjemi, Bergvesen og Metallurgi (før 1941 se T. f. K. og Bergvesen).
VIII (XXXVI) (XXVIII). 1948. s. 160—163: Mangansilikatmalmer i Ofoten.
IX (XXXVII) (XXIX). 1949. s. 177—182: Jomafeltet i Grong og dets malmforråd.
XI (XXXIX) (XXXI). 1951. s. 111: Direktør dr. phil. Carl Bugge (til 70-årsdagen 13. september).

Naturen.
LIV. 1932. s. 33—42: Geologiske undersøkelser omkring vore malmforekomster.

Det norske videnskapsakademi. Årbok 1950. s. 1—5: Minnetale over dr. C. W. Carstens.

Dagspressen.

Aftenposten.

1914. 15. og 18. februar: En fremsynt kulpolitik på Spitsbergen og Norges kulforsyning.

1932. 5. januar: Professor J. H. L. Vogts videnskapelige verdensinnsats.

Middagsbladet.

1914. 18. mars: Kulfeltene paa Spitsbergen. Disk.

Morgenbladet.

1914. 15. mars: Norges Kulforsyning og Spitsbergen. Ogsaa vi handler! Disk.

1918. 20. febr.: »Et folk i sorg, paa dødsens tog, av hver en ven forladt.«

—. 26. febr., 2. og 4. april, 14. mai: Gjennem det revolutionære Rusland og Sibirien.

Nationen.

1931. 12. desember: Anmeldelse av O. Holtedahl: Hvordan Norge blev til.

Utrykte arbeider.

For Norges geologiske undersøkelse foreligger praktisk talt ferdig til trykning følgende arbeider:

1. Kisdistriktet Varaldsøy—Ølve i Hardanger.
   Geologisk spesialkart i M 1 : 40 000 forelå trykt (1951). Videre forelå ferdig manuskript til den petrografiske beskrivelsen av bergartene, samt historik for de eldre driftsperiodene.
2. Kartbladet Frøyningsfjell, søndre del. Tekst mangler.
3. — Namsvatten, søndre del. Tekst mangler.
4. — Trones. Tekst mangler.
5. — Tunnsjø. Tekst mangler.
6. — Sanddøla. Tekst mangler.
7. — Nordli. Tekst mangler.
8. — Jævsjø. Tekst mangler.

9. Kartbladet Sørli. Tekst mangler.
10. — Bjørkvassklumpen. Tekst mangler.
11. — Nisser (her gjenstår en mindre del av bladet, som ikke er ferdig kartlagt). Tekst mangler.

Steinar Foslie har også befaret en hel rekke forekomster og verk i inn- og utland etter offentlig eller privat oppdrag og har også levert uttalelser om en rekke tekniske spørsmål. Den korte tiden har ikke tillatt en systematisk å oppsøke dem alle. Nedenfor nevnes bare de, som nærværende forfatter har kjennskapet til og som ikke er trykt.

1909. Spetalen (hematitt-)malmfelt i Vinger.
1913. Øvre Eiker. Sink, bly og kobber. Diverse skjerp.
— Innberetning til det Hielmstjernske-Rosencronske legat etter stipendiereise til Canada og U. S. A.
1914. Rollag molybdenforekomster i Numedal.
1915. Trelsgård jernmalmforekomst i Kvinnesdal.
1916. Betenkning vedr. manganproduksjonen i anledning kjøp av forekomster på Java.
— Baldoivi kobbermalmsforekomst i Saltdalen.
1917. Kjoresfjell og Kobbelven kobber-arsenkisforekomst i Skjomen. Kart.
— Moskehaugen kisforekomst i Balangen.
— Bjørkåsen forekomster i Ballangen.
1918. Bisperøenes jernmalmfelter, Hitteren.
— Helleknuten grafitt i Søndeled.
— Ekorndalen kobberforekomst i Søndeled.
— Espelands bly-sølvgrube i Vegårdshei.
— Tjongsfjord kromforekomst i Mo.
— Kalstad jernforekomst pr. Kragerø.
— Roen glimmerforekomst i Telemarken.
— Tovshus og Ukomdalen kobberforekomst i Mo i Telemarken.
1919. Escamillafeltet i Zaragoza, Spania.
— Anvendelsen av elektrisk kraft i Barcelona til elektrostålfremstilling.
— Undersøkelser av diverse malmforekomster i Spania.
1920. Melkedalen kisforekomst i Ofoten.
1921. Spansdalens grafittforekomst i Lavangen.
— Kasfjord arsenforekomst i Trondenes.
— Gamvik sink-blyforekomst i Lavangen.

— Tjelmarken kisforekomst i Ofoten.
1926. Rødsand jernmalmsforekomster (sammen med Carstens).
1927. Rapport over undersøkelser av titanoppredningsprodukter.
1934. Ørsdalen volfram- og molybdenforekomst.
1935. Rødsand jernmalmsforekomst. (10 karter.)
1937. Løvsjøli kisforekomst. Nordli.
— Skorovas kisforekomst i Grong.
— Heimtjønhø kisgruber i Kvikne.
1940. Søftestad jernmalmforekomst i Nissedal.
1941. Bruvann, Årnes og Råna nikkelforekomster i Rana.
1946. Forekomster i Ofoten.
— Kvænangen og Middavarre kobberkisforekomster.
1948. Kvandalen manganforekomst i Suldal.

Nekrologer over Steinar Foslie.

Aftenposten. 21. november 1951. Statsgeolog Steinar Foslie død. Red. —
— 24. november 1951. Statsgeolog Foslies død betyr et stort tap for norsk forskning. Av dr. Arne Bugge.
Journal. The Mining, CCXXXVII. No. 6067. Obituary: Steinar Foslie. (Av H. H. Smith.)
Morgenbladet. 20. november 1951. Statsgeolog Steinar Foslie død. Red.
Tidsskrift for Kjemi, Bergvesen og Metallurgi. XL. s. 188. Statsgeolog Steinar Foslie. Av dr. Carl Bugge.
Tidsskrift, Norsk Geologisk, 30 (XXX). 1951 s. 190. Minneord av dr. Carl Bugge.
Årbok (fra Det norske videnskapsakademi i Oslo). 1951. Minnetale av Carl Bugge.

PROFESSOR HANS CLOOS

Noen minneord.

Av Olaf Holtedahl

Med professor Hans Cloos som døde den 26. september 1951 nær 66 år gammel er en av den geologiske verdens sentrale skikkelser gått bort — og geologisk videnskap har litt et stort og smertelig tap.

Cloos var ikke bare en fremragende forsker innen sitt spesielle område, den endogene dynamikk med dens forskjelligartede strukturmessige manifestasjoner, han var også en særpreget og betydelig, allsidig begavet personlighet, en mann som i usedvanlig grad har virket stimulerende på geologer — vi kan si i alle land.

Ikke minst i hans »Einführung in die Geologie« av 1936 får man et sterkt inntrykk av hans originalitet, av hans evne til å trenge inn i det vesentlige i problemene og til i konsentrert form å gi en klar fremstilling av dem. Hans blokkdiagrammer og øvrige tegninger var mesterverker.

Blant de mange strøk av verden hvor han har foretatt studier og undersøkelser, var også Norge, og særlig Oslo-feltet, og i forskjellige skrifter har han gitt bidrag til dette områdes tektoniske geologi.

Kanskje allerstørst betydning har Hans Cloos hatt ved sitt virke gjennom mer enn 25 år som redaktør og forfatter i »Geologische Rundschau« hvor hans vide overblikk, hans initiativ og evne til å skaffe medarbeidere har resultert bl. a. i et utall av fortrinlige oversikter med belysning av spesielle, aktuelle emner.

Cloos' kunstneriske evner, ikke bare som tegner men også som forfatter, kommer i særlig grad frem i hans store bok fra 1947 »Gespräch mit der Erde« der han i rammen av personlige erindringer ruller opp for oss geologiske bilder i broget mangfoldighet — fra de forskjelligste egne av vår jord. Her er avsnitt av betagende virkning og alle er de preget av forfatterens dype hengivenhet for den videnskap hvor han har ydet så meget og som han nå er revet bort fra.

NOTISER

Iaktagelser i en skjæring i Vestfoldraet ved Larvik.

Den sydøstre delen av Larvik bøkeskog vokser på raet som her danner en utpreget rygg med relativt bratte skråninger mot øst og vest. Vestskråningen er brattest.

I forbindelse med undersøkelse av jordsmonnet i bøkeskogen ble det foretatt graving på flere steder også etter denne ryggen. Jordarten var her fra overflaten og ned til 50—70 cm grov grusrik sand med endel vel avrundet stein. Under denne dybde hadde jorda mer morenekarakter, men var for det meste så fast og hard at det var umulig å komme ned med spade.

For å få nærmere opplysninger om jorda i dypere lag undersøkte jeg en skjæring gjennom moreneryggen i det sydøstre hjørne av bøkeskogen, hvor Larvik kommune har et lite grus- og leirtak. Skjæringen er her etter midten ca. 8 m høy.

Profilet viser fra overflaten og nedover et 60—100 cm tykt lag av grusrik grov utvasket sand med avrundet småstein. Større og mindre blokker finnes i dette laget og stikker også fram i dagen. Videre nedover til 2,5—3 m dybde er det leirholdig stein og grusrik morenesand. Derunder blir leirinnholdet større så jordarten må nærmest karakteriseres som sand- og grusholdig leire.

På enkelte steder er det også skjellrester i dette nedre laget. Skjellene er for det meste sterkt oppknust og ikke lett å identifisere. Jeg fant imidlertid et par godt bevarte eksemplarer av *Yoldia arctica* og endel bruddstykker av samme art. Videre var det fragmenter som uten tvil måtte være *Saxicava arctica*. Dette nederste laget må derfor sies å være *Yoldialeire* med de samme skjellrester som en har funnet i leira i og utenfor raene andre steder.

Mekanisk analyse er utført i prøver fra de to lagene. Prøve I er uttat i 2 m dybde og II i 6,5 m dybde. Resultatene er gjengitt i etterfølgende tabell.

Prøve I har en sammensetning som den en ofte finner i vanlig usortert materiale av bunnmorene. Prøve II er grusholdig sandrik leire. Det er grunn til å tro at lagene over leira består av materiale som er avsatt under et framstøt av breranden.

Prøve nr.	Materiale større enn 2 mm i % av prøven.	De ulike kornstørrelser i % av materiale mindre enn 2 mm i diameter.						
		2.0—0.6 mm	0.6—0.2 mm	0.2—0.06 mm	0.06—0.02 mm	0.02—0.006 mm	0.006—0.002 mm	Mindre enn 0.002 mm
I	54	23.1	21.5	18.9	12.0	9.3	5.3	10.0
II	18	11.8	20.7	26.2	8.4	9.7	6.1	17.7

Det faste laget som ble iakttatt i bøkeskogen etter raryggen finner en også i skjæringen fra 60—100 cm under overflaten. Det strekker seg nedover til ca. 2 m dybde eller mer. Også leira under var relativt fast og hard.

Det harde laget er så fast at det er umulig å grave i det med spade. Klumper som en hakker løs er også ganske harde. Fargen er lys grå. I enkelte tilfelle kan en se fine brune årer. Tynnslip som er laget av slike faste klumper viser at sand- og gruskornene er omgitt av støvfint materiale som ser ut til å være impregnert av et gulbrunt kolloidmateriale.

Slike faste harde lag til dels av stor mektighet har jeg iakttatt også andre steder i raet ved Larvik, likeså i et grustak i raet foran Femsjøen i Idd ved Halden. Det er også et alminnelig fenomen i visse profiltyper i morenejord på Jæren.

Det faste laget er som nevnt lyst grått, i enkelte tilfelle med brune striper eller skjolder. Det har således et annet utseende enn vanlig aurhelle, som enten er rustbrun eller mørk brun til nesten svart ved mye humusutfelninger.

Vanlig aurhelle som opptrer i forbindelse med vel utviklede podsolprofiler på grovkornede avleiringer, er sjelden særlig tykk. Ofte opptrer den som noen få cm tykt fast sammenhengende lag med mørk glinsende farge. Annerledes er det med den type som professor Tamm kaller *allokton* aurhelle. Denne oppstår på steder hvor surt jern- og humusholdig vann, f.eks. avløp fra et myrområde, trenger inn i grove sand- og grusavleiringer. På slike steder kan det sammenkittede laget oppnå stor mektighet, men har som regel meget begrenset horisontal utbredelse. Noen slik dannelse er det vanskelig å tenke seg på et sted som oppe på raryggen ved Larvik.

Det er ellers en kjent sak at avleiringer av bunnmorene som inneholder endel leire og annet finmateriale som regel er meget tett og fast i dypere lag, gjerne så fast at det ikke går an å grave i den med spade.

Det store trykket av ismassene som slike avleiringer har vært utsatt for og den spesielle mekaniske sammensetning, er sannsynligvis en av årsakene til at bunnmorenene er så kompakte og faste. Men når det faste harde laget forekommer like opp til 40 cm fra overflaten som jeg har observert i visse profiler på Jæren og når jorda blir løsere dypere nede i profilet, kan sammenpresning som følge av istrykket ikke være noen tilfredsstillende forklaring på dette forholdet.

Slike faste harde lag et stykke fra overflaten forekommer bare på steder hvor jorda er relativt godt drenert. Jordprofilet har gjerne følgende utseende: øverst et humusholdig lag, derunder et brunt, nærmest rustbrunt lag og så et lysere hardt sammenpakket og sammenkittet lag av forskjellig tykkelse. Under dette er det kompakt grå bunnmorene.

I profiler på fuktige steder hvor grunvannet står høyt, finner en derimot så vidt en hittil har undersøkt, ikke noe fast lag selv om avleiringene ellers er fullstendig like. Trykket av isen må jo ha vært det samme, så i hvert fall for endel må en gå ut fra at jordsmonndannende faktorer har medvirket ved dannelsen av disse faste harde lagene.

Disse dannelser er ennå for lite undersøkt til at en kan gi noen fullt tilfredsstillende forklaring på hvorledes de er oppstått.

Ved omfattende jordbunnskartlegging som er utført i Nordøst-Skottland har det vist seg at faste harde lag (*indurated layers*) er alminnelige på morenejord som er vel drenert. Det faste harde laget forekommer der i forskjellig dybde fra overflaten under et brunt lag. Det har mer grå farge enn det brune laget. Porevolumet er ca. 20 % i det faste laget mot ca. 50 % i det brune løse laget. Innholdet av leir har vist seg å være mindre enn i lagene over og under. Kjemiske analyser viser at det har foregått en akkumulasjon av aluminium-hydroksyd i det faste laget, slik at dette inneholder mer aluminium i forhold til jern enn laget over.

Selve sammenkitningen tilskrives en herdning av kolloidmateriale som er ført nedover med synkevann fra de øvre lag.

Det er også av interesse å notere at tilsvarende dannelser er beskrevet i vårt land i 1911 av A. Monrad Rom i en beskrivelse av jordbunnen i østre deler av Aust-Agder fylke.

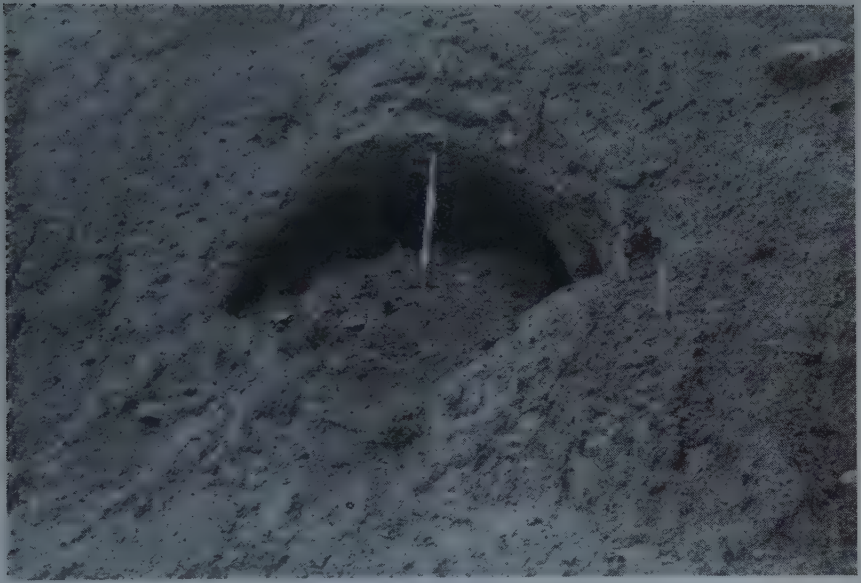
Om morenegruset i Åmli og Vegårdshei skriver Rom: »Det er ofte sammenkittet til aurhelle som i disse bygder kalles *mol.* Etter de undersøkelser jeg har foretatt opptrer molen i to farger: rødbrun og gråhvit. Den første er den alminneligste og er kalt *raumol* den annen *kvitmol.* Begge kan bli temmelig harde og ugjennomtrengelige. Ved forsøk på laboratoriet viste det seg dog at de smuldrer noe ved å bli utsatt for luft og vekslende fuktighet og tørke. Raumolen ligner alminnelig aurhelle, og bindemidlet synes å være jernoksydhydrat. Kvitmolen er stenfri, og sammenkitningsmaterialet er mer vanskelig å bestemme, det synes å være et lerholdig stoff. De danner begge en hard og ugjennomtrengelig undergrunn.«

Rotutviklingen synes også å være noe annerledes på jord med et lyst grått sammenkittet lag enn på egentlig aurhelle. I skjæringer ved Larvik kan en se hvorledes trerøttene er i stand til å trenge gjennom det faste laget. Rundt røttene danner det seg et løst lag eller en tynn

stripe med løs jord fra 3—4 cm til noen få mm i diameter. På overgangen mot det faste laget er det gjerne en brun sone. Om røttene virkelig er i stand til å trenge gjennom det faste laget, eller de søker ned gjennom opprinnelige sprekker er selvfølgelig ikke godt å avgjøre. Alminnelig aurhelle synes røttene derimot å ha meget vanskelig for å trenge igjennom. I slik jord ligger røttene som en matte ovenpå aurhellelaget.

At jorda er fast og kompakt i en viss dybde har også praktisk betydning. Gjennomtrengeligheten for vann er mindre. I nedbørrikt klima vil det derfor trenges sterk drenering. Drenering faller selvfølgelig kostbar når en må hakke gjennom et tykt fast lag. Hvor det faste laget forekommer så høyt oppe som 40—50 cm fra overflaten, ser det ut til at visse vekster vokser dårligere enn der jorda er løs og lett gjennomtrengelig til større dybde.

Vi vet ennå lite om utbredelsen av denne jordtype i vårt land. Det vil derfor være av interesse om geologer og andre som har høve til å undersøke skjæringer på forskjellige steder i landet, er oppmerksom på disse dannelser og gjør notater om utseendet av profilet, tykkelsen av de ulike lag, forekomst av fast lag, begrensningen oppad og nedad fra dette, fuktighetsforholdene m. m. Materiale som samles på den måten og offentliggjøres vil gi opplysning om hvor i landet vi kan vente å finne disse dannelser og være til stor nytte ved en eventuell senere mer systematisk undersøkelse av forholdet.



I det samme leirtaket ved Larvik la jeg også merke til et annet forhold som jeg vil nevne.

Omtrent midt i skjæringen, ca. 2,5 m fra overflaten er det et stort hull eller nærmest en port inn til en hule. Dimensjonene på åpningen er 1,8 m i tverrmål, 1,2 m i høyde, og dybden på hulen er ca. 1,8 m. Formen og beliggenheten går fram av fotografiene.

Ifølge opplysninger fra folk som bor like ved skjæringen (Øvre Bokeligt. 19), ble en først oppmerksom på dette hullet våren 1950. Da de var redd hulen skulle rase sammen og forårsake ulykke med barn som lekte der, ble hulen fylt med jord.

Da jeg besøkte stedet (17. juli), var det derfor ikke godt å få full oversikt over hulen. Men vi skuffet bort endel jord så vi fikk målt dybden og undersøkt veggene og bunnen. Jorda var fast og hard i vegger og tak.

Med hensyn til hvorledes et hull som dette kan være oppstått, ligger det nærmest å anta at det er hull etter en stor blokk som har vært innleiret i morenematerialet og som har løsnet og falt ut fra skjæringen. Men det var ikke noe å se til en slik blokk i leirtaket under hullet. Jeg spurte folk som bor like ved og folk som arbeider i leirtaket om de hadde lagt merke til noen stor blokk i skjæringen på dette stedet. Men ingen av dem kunne huske å ha lagt merke til noen slik.

En ble som nevnt oppmerksom på hullet våren 1950 etter at det hadde foregått en liten utglidning der. Enkelte som jeg snakket med mente at hullet til å begynne med var mindre enn da jeg var der.

Hvis dette ikke er hull etter en stor blokk som er falt ut, er det ikke godt å si noe sikkert om hvorledes det kan være oppstått. Det er spørsmål om det da kan være hull etter en isblokk som er løsnet fra brekanten og er blitt begravet av løsmateriale tilført av breelvene eller etter is som er blitt innleiret i materiale skjøvet sammen under et framstøt av isranden. Noe sikkert svar på et spørsmål som dette kan en ikke vente å få. Det er dessverre for usikre opplysninger om forholdene på stedet da hulen først ble synlig og for mange ukjente forhold til det. Fenomenet er så interessant at jeg allikevel har villet nevne det her.

G. Semb.

Litteratur.

Glentworth, R., 1944: Studies on the soils developed on basic igneous rocks in Central Aberdeenshire. Trans. Roy. Soc. of Edinburgh. Vol. LXI, Part I.

— and Dion, H. G., 1949: Hydrologic sequence in soils of podzolic zone. Journ. of Soil Science I, 35—49.

Rom, Monrad, A., 1911: Jordbunden i de østre dele av Nedenes amt. Jordbundsbeskrivelse Nr. 3.

Occurrences of Zeolites in Nordmøre.

Recently in this journal (vol. 28, p. 50, 1949) E. Sæther announced the occurrence of the zeolite mineral laumontite in a granodioritic gneiss near Tingvoll, Nordmøre, north-western part of Southern Norway. In the parish of Todal in the same district, at the road just north of Todalshaug (62° 49′.7 N, 2° 1′. W Oslo or 8° 42′ E Gr.), the writer in 1948 collected a sample of a pink-coloured, soft and friable rock, occurring as a vein of about 10 cm thickness on a vertical cross-joint in a gneiss (sample E26v 107, Geol. Survey of Norway). Examination of this vein-rock in a thin section and in powder showed the presence of two minerals certainly of the zeolite group, referred to as z1 and z2 in the following description. Besides the zeolites the vein mass contains quartz, greenish biotite and epidote. The form and arrangement and the abundance of the quartz grains indicate this mineral as a relic from a gneiss, and the same is probably the case with the biotite and epidote, while the zeolites may have been formed at the expense of the feldspars of the gneiss.

The zeolites, which make out the bulk of the vein mass, form a matrix with grains size about 0.05 mm and larger insets of 0.2 to 0.5 mm size. They are turbid from a brownish, probably limonitic substance, which certainly is the cause of the reddish colour of the rock. It is of some interest to note a bending of the cleavage cracks and an undulous extinction of the grains, indicating some tectonic influence.

z1. The grains with two cleavages nearly at right angle, cleavage cracks distinct and narrow and closely spaced, with the axial plane in a diagonal position between the cleavages. Measurements on the universal stage showed a surprisingly great variation in the optical orientation, as values between 10° and 80° were found of the angle between c (the axis of the cleavages) and γ. The measurements (eight in all) can not be claimed to be very accurate, but they ought not to be absurdly wrong. — 2 V varying between 30° and 60° with dispersion $r < v$, $\gamma > 1.500 > \alpha$. The birefringence is of the same order of magnitude as in quartz. — The cleavages and optical orientation indicate a monoclinic mineral similar to the zeolites laumontite and scolectite, but the refringence is lower than in these minerals.

z2. The grains with two cleavages at right angle, appearing as rather widely spaced partings often filled with a dark substance. Sections normal to the two cleavages show α in the center of the field and the axial plane in the more marked cleavage, the other less distinct cleavage thus $\perp \gamma$. This has been confirmed by observations with the Fedorow stage and also by the very common occurrence in powder preparations of grains with β, or less commonly γ, in a normal position. — 2 V varying between 30° and 60°, dispersion $r < v$. The birefringence is lower than in z1. In some instances grains of this mineral show zoning (refringence core < rim). Also in powder preparations a variation in refringence has been observed, γ varies from about 1.475 to 1.485 or more, α is about 1.475 or less. — — In its orthorhombic type of cleavages and optical orientation the present mineral resembles the zeolites ptilolite and epidesmine, being nearer to the former.

In the geological collection of the Agricultural College of Norway there is a specimen of a pink-coloured gneiss from Raudberget (»Red Rock«) near the farm Todal in the parish of Aure (63° 12′ N, 2° 1′.5 W Oslo or 8 ° 42′ E Gr.). The rock has an un-fresh appearance and the greater parts of it can be easily scratched with a knife. In a section the rock is seen to contain quartz, unaltered potash feldspar and biotite, while the plagioclase is wholly decomposed. A mineral with cleavages and optical orientation like z1 in the Todalshaug vein occurs in subordinate amounts. In powder preparations probably the same mineral was found, showing prismatic cleavages, an angle of about 30° between γ and the cleavage axis, $1.520 > \gamma > 1.500$, α — 1.500.

On his excursions in Nordmøre the writer had noticed the common occurrence of reddish films on joint surfaces in the gneisses, which might be suspected as being due to the deposition of zeolites. Recently opportunity offered to sample a specimen from such a reddish joint surface in a gneiss at the road between Kvanne and Stangvik (62° 54′ N, 2° 14′.5 W Oslo or 8° 29′ E Gr., sample E28v 169). Joints in a micaschist at Glærum in Surnadal (62° 59′.4 N, 2° 6′ W Oslo or 8° 37′ E Gr., E26v 178) was found to be covered with numerous grains of a light well crystallized mineral.

The minerals occurring at the joints at the two localities just mentioned showed similar characters: good prismatic cleavages, an optical orientation of a monoclinic type with an angle of about 30° between γ and the cleavage axis, — 2 V small, $\gamma > 1.500 > \alpha$.

The observations recorded just above seem to indicate that zeolites will be found to occur at numerous localities in these regions, when only looked for. As emphasized by Sæther, it will be of interest to know the regional distribution of the zeolitization. The gneisses of Nordmøre are most probably of a Caledonian age and the micaschist mentioned above is undoubtedly Caledonian. The zeolitization in these districts must thus be late Caledonian or younger. A connection between the zeolitization and late Caledonian tectonic movements seems no unreasonable assumption.

Geological Survey of Norway, October 1951.

Trygve Strand.

Larsen, Esper S. and Berman, Harry: The microscopic determination of the nonopaque minerals. 2nd edition. U. S. G. S. Bull. 848, 1934.

En etterlysning.

For en tid tilbake fikk Geologisk institutt ved Universitetet i Bergen tilsendt en prøve fra en flyttblokk som var funnet på toppen av Midthamarsåta, det høyeste fjell på Stord i Sunnhordland, 750 m o.h. Bergarten er en kvartsitt med en eiendommelig rosa farge, som ved undersøkelse i mikroskop viste seg å skyldes en manganholdig epidot. Da manganepidoter er forholdsvis sjeldne, skulle en slik bergart egne seg godt som ledeblokk. Ingen av instituttets vitenskapsmenn hadde imidlertid sett en slik bergart i naturen, eller hadde noe kjennskap til den fra litteraturen. I sommer ble jeg oppmerksom på at *T. Strand* har beskrevet en thulittførende sparagmitt fra Bollhaugen i N. Etnedal (N. G. U. Nr. 152 s. 43). Ved elskverdig imøtekommenhet fra Strand fikk jeg utlånt en prøve av bergarten, og fikk samtidig en liknende bergart fra Svarthammeren på kartbladet Slidre. Det viste seg imidlertid at disse bergarter er vesentlig forskjellige fra flyttblokken. Mens denne er en finkornet, nesten feltspatfri kvartsitt, er Strands bergarter typiske sparagmitter, med rikelig feltspat og med en forholdsvis beskjeden rekrystallisasjon. Den manganholdige epidot er heller ikke identisk i disse bergarter. Det synes derfor helt utelukket at kvartsitten på Midthamarsåta kan være kommet fra Valdres.

Da det ville ha stor interesse å få rede på hvor blokken er kommet fra, skal jeg få gi en kort beskrivelse av bergarten, i håp om at noen av leserne skulle kjenne til en slik bergart.

Kvartsitten er jevnt finkornet, med gjennomsnittlig kornstørrelse omkring 0,1 mm. Strukturen er granoblastisk, med fullstendig rekrystallisasjon. I håndstykke virker den massiv, men i tynnslip kan sees en viss parallell orientering, og de mørke mineraler er delvis samlet i bånd.

Kvarts utgjør 65—70 % av bergarten og har undulerende utslukning. Manganepidot utgjør ca. 25 %. Den har pleokroisme X gul, Y rosa, Z rosa, og dobbeltbrytning Ng—Np ca. 0,025.

Ved siden av de to hovedmineraler inneholder bergarten en fargeløs amfibol, små mengder av kalifeltspat og kalkspat, samt noen få korn av apatitt og sirkon.

Hvor en skal lete etter en slik bergart, er ikke godt å si, men det ligger kanskje nærmest å tenke på Telemarkformasjonen.[1]

Bergen, 24. oktober 1951.

Anders Kvale.

Litteratur.

Fra forlaget Akadémiai Kiadó, Budapest, er innsendt til redaksjonen László Tokody and † Maria Dudich: *Meteorite-Collections in Hungary,* 1951. 108 sider. Ungarsk, russisk og engelsk tekst.

Det er en katalog over det meget omfattende meteoritt-materiale som finnes i ungarske samlinger. Katalogen gir for hver meteoritt: lokalitet, klassifikasjon, vekt, og årstall for fall eller funn. Materialet er katalogisert to ganger, nemlig først etter lokaliteter i alfabetisk rekkefølge, og deretter systematisk etter Prior. Hovedsamlingen finnes i det ungarske nasjonalmuseums mineralogiske avdeling og omfatter nå 1295 meteoritter fra 484 fall-lokaliteter; den er en av de viktigste meteoritt-samlinger i verden. En innledning omtaler kort denne samlingen og dens historie. Mindre samlinger finnes i Eötvös-Loránd-universitetets mineralogske institutt i Budapest (142 meteoritter, 24 lokaliteter), i Budapest tekniske høgskoles mineralogisk-geologiske institutt (3 meteoritter), i Calvinist College i Debrecen (37 meteoritter, 17 lokaliteter), i Jósa András museum i Nyiregyháza (2 meteoritter). Katalogen gir også en liste over synonymer for fall-lokaliteter.

Boken har stor interesse for dem som arbeider med meteoritter, og særlig for dem som har med større meteorittsamlinger å gjøre.

Ivar Oftedal.

---

[1] Under ekskursjoner i forbindelse med årsmøtet i Norske Naturhistoriske Museers Landsforbund i Stavanger 7. og 8. mars 1951 ble funnet to løse blokker som inneholdt manganepidot.

Den ene ble funnet på Smørpiggen nær Bråstein i Høyland, i en moreneavleiring hvis materiale sannsynligvis er kommet østfra. Den er en middelskornet kvartsitt med litt kloritt og 20—30 % Mn-holdig epidot.

Den annen prøve ble funnet løs i Graverens Teglverk på Sandnes. Den er en middelskornet mikroklingranitt, som synes å være sekundært impregnert med manganepidot.

Disse funn tyder på at det et sted øst for strekningen Stord—Jæren finnes et område med kvartsitt og granitt som er blitt impregnert med manganholdig epidot.

NORSK GEOLOGISK FORENING

Møte 331. Torsdag 12. april 1951.

Tilstede 29 medlemmer og 6 gjester.

Innvalg:

(344) Lektor *J. H. Archer,* Åsen Terasse 2 B[2], Horten, foreslått av H. Neumann og S. Føyn.

(345) Stud. mag. scient. *Finn Skjerlie,* Roald Amundsens vei 97, Bergen, foreslått av T. Barth og H. Neumann.

(346) *Chen Kwan Yuan,* B. Sc. Geologicum, Uppsala, foreslått av G. Henningsmoen og N. Spjeldnæs.

(347) Stud. real. *Natascha Heintz,* Presteveien 84, Blommenholm, foreslått av G. Henningsmoen og N. Spjeldnæs.

Olge Adamson holdt kveldens foredrag: »*Våre mineralske råstoffers geopolitiske betydning.*« I ordskiftet etter foredraget deltok: P. Holmsen, B. Dietrichson, H. Bjørlykke, H. Rosendahl, O. A. Broch, T. Gjelsvik, J. Braastad og foredragsholderen.

Møte 332. Tirsdag 8. mai 1951.

Tilstede 25 medlemmer og 6 gjester.

Innvalg:

(348) Cand. mag. *Fredrik Huseby,* Geologisk institutt, Blindern, foreslått av G. Henningsmoen og N. Spjeldnæs.

Fil. dr. *Sigurdur Thorarinsson* holdt kveldens foredrag: »*Myvatnområdets lavaströmmar och kratergrupper.*« I ordskiftet etter foredraget deltok: W. Werenskiold, T. Barth, H. Rosendahl, O. A. Broch, B. Dietrichson, P. Holmsen og foredragsholderen.

Møte 333. Torsdag 25. oktober 1951.

Tilstede 20 medlemmer og 6 gjester.

Innvalg:

(349) Dr. *André Ph. Sandrea* (attaché de rechèrche), Laboratoire de Minéralogie, Musée Nation. Hist. Natur. Paris 5, foreslått av Chr. Oftedahl og O. Holtedahl.

Ivan Th. Rosenqvist holdt kveldens foredrag: »*De metamorfe fasies og feldspatmineralene.*«

V. M. Goldschmidt formulerte den modifikasjon av W. Gibbs' faseregel som siden er blitt kalt »Den mineralogiske faseregel«. Denne modifiserte faseregel forutsetter at en bergart som er i likevekt, må ha to frihetsgrader, altså være stabil inen et visst trykk/temperaturintervall. Komponenter som kan erstatte hverandre isomorft i de foreliggende faser, regnes ikke som særskilte komponenter, men som en komponent. Et eksempel på dette er at Fe^{II} og Mg regnes som *en* komponent i olivin- eller pyroksenførende parageneser, mens en i talkførende parageneser må regne dem som to komponenter.

På samme måte som V. M. Goldschmidt gjorde det, bygget Eskola sine fasies-undersøkelser på antagelsen av at fysikalsk-kjemisk likevekt er vanlig i de metamorfe og eruptive bergarter. Det forhold at faseregelen gjelder i så mange tilfelle, berettiger til denne antaglse. Eskolas fasiesprinsipp er en av de største landevinninger innen metamorfoseforskningen. Hans fasieslære vinner stadig terreng og har i mange tilfelle vist seg meget nyttig. I enkelte bergarter synes prinsippet imidlertid å svikte.

Det finnes av og til velkrystalliserte metamorfe bergarter med mineralkombinasjoner som strider imot de Eskola anerkjente. Det er liten grunn til å forkaste disse bergarter ved å anta at de er i ulikevekt. Man bør søke å tillempe fasieslæren slik at den får genenell gyldighet.

Eksempler på bergarter som ikke tilfredsstiler Eskolas fasieslære har en i Bambleformasjonens sillimanittgneiser og enkelte labradorsteiner på Vestlandet, der paragenesen plagioklas, zoisitt, hornblende, pyroxen forekommer. Disse bergarter tilfredsstiller faseregelen dersom vann regnes med som komponent, likeverdig med de øvrige oksyder.

Eskolas fasieskriterier lider etter min mening av en utpreget skjønnhetsfeil, idet de forutsetter fullstendig vannmetasomatose for å komme til uttrykk. I svært mange metamorfe bergarter er denne forutsetning ikke tilstede. For den eksakte behandling av metamorfoseproblemene er det også uheldig at Eskola har bygget sitt system på variasjoner i de mørke mineraler. De krystallkjemiske forhold for disse er uhyre kompliserte, og vi har intet håp om at de skal bli tilnærmelsesvis klarlagt i vår generasjon.

For å søke å bringe Eskolas strålende idé i overensstemmelse med fysikalsk-kjemiske kjensgjerninger, er det jeg har utført de undersøkelser som skal omtales her.

Først var det nødvendig å identifisere Eskolas fasiesområder i et termodynamisk koordinatsystem. Dette synes mulig, idet en må anta at stress kun har innflytelse som katalysator. De fasiesområder som er ansett for å være de viktigste er: grønnskiferfasies, epidot-amfibolittfasies (saussuritfasies), amfibolittfasies, sanidinittfasies, granulittfasies og eklogittfasies.

En del av de fasiesoverganger som opprinnelig ble fastsatt av Eskola, er ikke definerbare i et PT-diagram, idet innflytelsen av variabel kjemisk sammensetning ikke inngår som fasieskriterium. Det er derfor bare med en viss tilnærmelse man kan bestemme trykk/temperatur-arealet for de fleste av Eskolas fasies, selv om de enkelte mineralers krystallkjemiske forhold hadde vært klarlagt i detalj.

Fasiesgrensenes vinkelkoeffisient i et PT-diagram vil være definert ved volumendringen og varmetoningen ved fasiesovergangen. Clausius-Clapeyrons likning må imidlertid brukes med forsiktighet så lenge man ikke kjenner entropi- og volumendringene for de enkelte mineraler som funksjon av temperatur og trykk. Inntil disse kalorimetriske og volumetriske undersøkelser er utført, kan Clausius-Clapeyrons likning bare tas som et semikvantitativt uttrykk for le Chateliers prinsipp.

Dersom varmetoningen ved en fasiesovergang er stor i forhold til volumendringen vil fasiesgrensen forløpe subparallelt P-aksen i et PT-diagram. Dersom varmetoningen er liten i forhold til volumendringen, forløper fasiesgrensen subparallelt T-aksen. Dersom forholdet mellom varmetoning og volumendring hverken er stort eller lite, vil fasiesgrensen danne midlere vinkler med P- og T-aksene.

Ved følgende fasiesoverganger kan vi regne oss til at varmetoningen er stor i forhold til volumendringen:

1. Overgangen grønnskiferfasies—epidot-amfibolittfasies.
2. — epidot-amfibolittfasies—amfibolittfasies.
3. — amfibolittfasies—pyroxen-hornfelsfasies.

Disse fasiesgrenser vil derfor forløpe subparallelt trykkaksen i et PT-diagram. Avvikelsen fra parallellitet med trykkaksen er størst for den førstnevnte av disse overganger og minst for den sistnevnte. Ved hjelp av laboratorieundersøkelser som er utført dels ved Universitetet i Bergen og dels ved Forsvarets Forskningsinstitutt, mener jeg å kunne bestemme omvandlingstemperaturen ved 1 atm trykk for disse overganger til henholdsvis ca. 200° C, ca. 400° C og ca. 750° C.

Overgangen pyroxen-hornfelsfasies til sanidinittfasies finner sted under liten volumøkning og meget liten varmetoning. Denne fasiesgrense må derfor forløpe slik at økende trykk relativt raskt øker omvandlingstemperaturen. De beregninger som er utført gir gradienter for omvandlingstemperaturen på ca. 0,4° C pr. atm ved ca. 1000° C. Ved 1 atm antas denne omvandling å finne sted ved ca. 875° C.

Overgangen amfibolittfasies/granulittfasies finner sted under stor volumendring og stor varmetoning. Denne fasiesgrense forløper slik at økende trykk minsker omvandlingstemperaturen. Det er her ikke mulig å ha noen bestemt idé om forløpet av denne fasiesovergang på grunnlag av eksperimentelle data. Tar man forskjellige geologiske indikasjoner med i betraktning, kommer en til at en muligens kan anta en senkning av omvandlingstemperature på ca. ¼° pr. atm. Selv ved de høyeste temperaturer får en visstnok ikke granulittfasies-paragense ved mindre dyp enn 6 km. Dette vet vi dessverre lite om.

Jeg kan ikke være enig i at eklogittfasies eksisterer som noe definerbart uttrykk for trykk og temperatur. Eklogittene er etter mitt

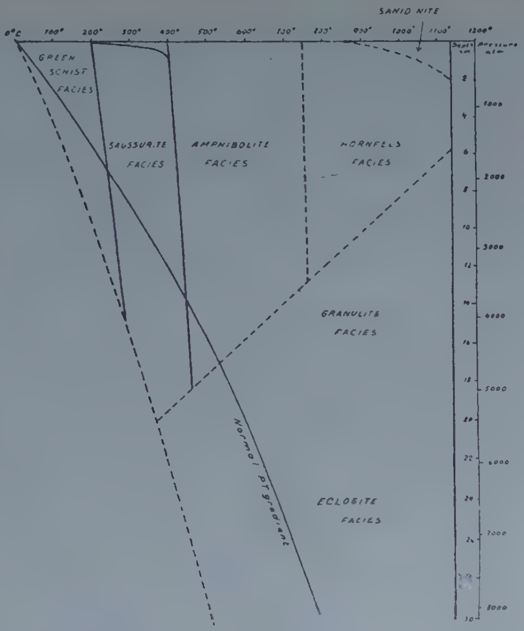


Fig. 1. Stabilitetsområdene for Eskolas metamorfe fasies.

syn kun representanter for basiske bergarter metamorfosert i granulittfasies.

Sammenfatter en det som ovenfor er sagt om de forskjellige fasiesoverganger med det en vet om temperatur- og trykkforholdene i jordskorpen, kan en konstruere følgende eksistensområder (fig. 1).

Som en ser angis den normale PT-gradient i jordskorpen med en helt opptrukket linje. Til høyre for denne linje har en alle de trykk/temperatur-kombinasjoner som kan oppstå der det er magmatisk aktivitet. Til venstre for den opptrukne linje har en de PT-kombinasjoner som kan forekomme i sedimentære bergarter i et geosynklinalområde uten magmatisk aktivitet. Det er ingen prinsipiell forskjell mellom de kontaktmetamorfe fasies og de dynamometamorfe fasies.

Etter å ha bestemt beliggenheten av de forskjellige Eskolas fasiesarealer i et PT-diagram under forutsetningen av ideell vannpermeabilitet i bergartene, vil vi se på noen svakheter ved systemet. Det er for eksempel åpenbart at forskjellige hornblendemineraler klorittiseres under forskjellige termodynamiske betingelser selv om man forutsetter ideell vannpermeabilitet i bergarten. Det er likeledes sikkert at for eksempel en labradorfeldspat saussurittiseres under andre betingelser i en kalkspatførende paragenese enn i en kalkfattig paragenese. Det er likeledes en kjensgjerning at rhombisk og monoklin pyroxen ikke uralittiseres samtidig i våre norittiske bergarter

Eskolas fasiesoverganger tilfredsstiller ikke betingelsene for kjemisk invariabilitet, og de er basert på reaksjoner hvori de mørke mineraler inngår som hovedkomponenter. Reaksjoner som ikke forutsetter metasomatose og som kan fastlegges entydig krystallkjemisk, må ansees å ha fordeler fremfor Eskolas system dersom de på samme måte som dette dekker de PT-betingelser som kan forekomme i jordskorpen. Selv om alle de overganger jeg i det følgende vil berøre ikke er kjent i detalj, så er de dog av den art at de *kan* erkjennes eksperimentelt, og fremfor alt at de tilfredsstiller betingelsene for kjemisk invariabiliteet.

For å begynne med de høyeste temperaturer kan vi ta overgangen fra sanidinittfasies til pyroxen-hornfelsfasies. Denne grensekurve er også etter Eskola definert kjemisk invariabel. Etter moderne undersøkelser synes overgangen fra kali-natron ortoklas til kali-natron sanidin å være betinget av en interdiffusjonsprosess mellom Al og Si. Prosessen er meget følsom for stigende temperatur, men meget treg for synkende temperatur. Den egner seg av denne grunn godt som fasieskriterium. Angående trykk- og temperaturforholdene for transformasjon, så er disse allerede nevnt.

I stedet for de meget usikre og kjemisk betingete kriterier vi har for overgangen fra pyroxen-hornfelsfasies til amfibolittfasies, foreslår jeg å bruke høytemperatur/lavtemperatur plagioklas omvandlingen som kriterium. Denne transformasjon er antagelig analog til sanidinomvandlingen. Varmetoningen er imidlertid betydelig, hele 9 cal pr. g og volumendringen meget liten. I PT-diagrammet får derfor denne omvandling samme vinkelkoeffisient som uralittiseringsprosessen. Temperaturen synes å være noe lavere, nemlig ca. 700° mot 750° for uralittiseringen. Plagioklasomvandlingen er også meget ømfintlig indikator på oppvarming og relativt treg indikator for avkjøling, selv om den p.g.a. den meget større omvandlingsvarme ikke er fullt så treg som sanidinomvandlingen. På grunn av at jeg nå foreslår en litt annen temperatur som grensetemperatur, må det også skje en endring i nomenklaturen. Jeg foreslår at betegnelsen pyroxen-hornfelsfasies erstattes av betegnelsen hornfelsfasies. For den fasies som representerer det lavere temperaturområde, foreslår jeg betegnelsen høygneisfasies. Denne fasies er karakteristisk ved at plagioklasen har lavtemperaturoptikk. Kalifeldspatene er enten mikroklin eller ortoklas. Som oftest opptrer pertitter i feldspatene. I temperaturområdet ned til ca. 400° C er disse pertitter for det meste av strengpertitt-typen. Dette omtalte jeg i et foredrag jeg for et par år siden holdt i denne forsamling.

Ved ca. 400° har en som nevnt, overgangen mellom amfibolittfasies og epidot-amfibolittfasies (saussurittfasies). Denne grense er meget vanskelig å definere, idet variasjoner i bergartens Fe^{III}/Al forhold har stor innflytelse. Samtidig med denne fasiesomvandling, skjer det en endring i pertittypen. Under 400° dannes såvel avblandingspertitter som replacements-pertitter i form av film- og årepertitter. For bergarter der pertitter av denne type dannes, foreslår jeg be-

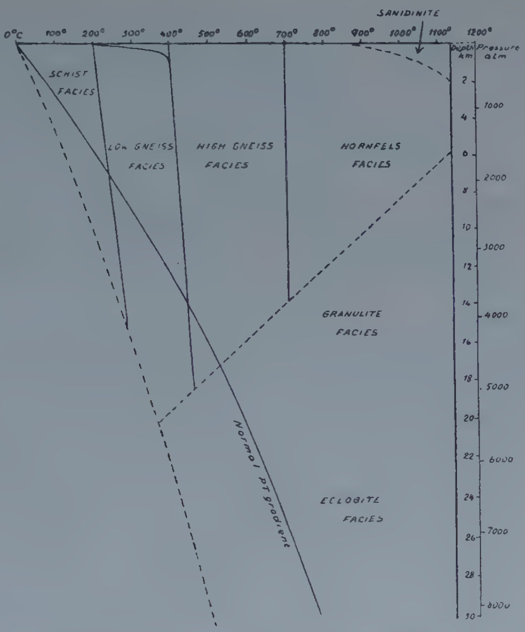


Fig. 2. Stabilitetsområdene for de foreslåtte metamorfefasies basert på feldspatmineralene.

tegnelsen lavgneisfasies. Ved de laveste temperaturer dannes pertitter av den uregelmessige flekk-pertittypen. Dette temperatur/trykk-område svarer til grønnskiferfasies. Jeg foreslår skiferfasies, idet jeg dermed vil betegne at det ikke bare er i grønnskifre, men også i glimmerskifre og andre bergarter en kan finne likevektstilstander som svarer til disse PT-forhold.

Selvsagt er ikke alle bergarter som jeg henfører til skiferfasies, lav- eller høygneisfasies folierte, men det vil dog være et overveiende antall av bergarter som er omvandlet under disse forhold, som har slik struktur.

For overgangen til granulittfasies har vi ikke tilstrekkelige fakta å bygge på. Vi får derfor fortsatt regne med at denne transformasjon er definert ved at biotitt dekomponerer i kalifeldspat og granat, og at kalifeldspaten smelter eller oppløses i porevannet.

Det system jeg i det foregående har skissert, kan sammenfattes i fig. 2. Som vi ser, adskiller det seg i sitt utseende meget lite fra fig. 1.

Fordelen ved systemet er etter min mening, at en her har et fasiessystem som er uavhengig av at det samtidig med metamorfosen skal finne sted metasomatose. Det står ennå tilbake å undersøke brukbarheten av det foreslåtte fasiessystem på et tilstrekkelig antall lokaliteter. Foreløbig har jeg ved mine arbeider på Vestlandet og i Opdal—Lesja-området ikke funnet noe som tyder på at systemet ikke er brukbart.

I en samlende avhandling som nå er levert til trykk i Bergens Universitets Årbok, beskrives de laboratorieforsøk som ligger til grunn for dette foredrag, og en utfyllende litteraturliste er gitt.

I ordskiftet etter foredraget deltok Chr. Oftedahl, H. Bjørlykke, S. Foslie, T. Strand, O. Holtedahl, O. A. Broch og foredragsholderen.

Møte 334. Torsdag 22. november 1951.

Tilstede 33 medlemmer og 4 gjester.

Forsamlingen mintes *Steinar Foslies* bortgang.

Innvalg:

(350) *Donald Baker* B. Sc. Princeton University, Department of Geology, New Jersey, U. S. A., foreslått av Olav Liestøl og Harald Major.

O. A. Broch henstillet til styret at det innarbeides som fast kutyme at foredragsholderen i god tid innbys til foreningens uformelle sammenkomst etter møtet. Innbydelsen bør gis en slik form at ingen kan være i tvil om at foreningen setter megen pris på foredragsholderens nærvær. Det vil ikke være av veien om den gis skriftlig.

Prof. dr. *A. Heintz* ga en kort meddelelse om »*et nytt funn av mammutt-tann i Norge*«.

Prof. dr. *P. Thorslund* (Uppsala) holdt et kort foredrag om »*Släktet Robergias systematiska ställning*«. Etter foredraget ytret ytret L. Størmer og G. Henningsmoen seg.

Cand. real. *Steinar Skjeseth* holdt kveldens hovedforedrag: *Stratigrafi og tektonikk i Mjøstraktene*«. I ordskiftet etter foredraget deltok: O. Holtedahl, P. Thorslund, L. Størmer, H. Rosendahl, T. Gjelsvik, Chr. Oftedahl og foredragsholderen.

Møte 335. Torsdag 13. desember 1951.

Tilstede 25 medlemmer og 16 gjester.

Innvalg:

(351) Dr. *O. M. B. Bulman,* Sedgwick Museum, Cambridge, England, foreslått av L. Størmer og G. Henningsmoen.

(352) Fil. lic. *Nils Marklund,* Gruvförvaltningen, Boliden, foreslått av G. Henningsmoen og N. Spjeldnæs.

Kveldens foredrag var: 1) *Tore Gjelsvik:* »*Fra en reise i U. S. A.*« (med fargelysbilleder. 2) *Chr. Oftedahl:* »*En tripp gjennom U. S. A.*« Kåseri med fargelysbilleder.

Ekstraordinært møte 336. Onsdag 6. februar 1952.

I Geografisk Auditorium, Blindern.

Tilstede 25 medlemmer og 16 gjester.

Foredrag av Ing. *Hans Lundberg* (Toronto): »*Geofysisk malmleting fra luften*«. I ordskiftet etter foredraget deltok: S. Føyn, ing. K. Hollan-Hagen, O. Adamson, dir. Viggo Widerøe, dir. H. Brækken, H. Bjørlykke og foredragsholderen. Deretter takket T. Barth foredragsholderen på foreningens vegne.

Generalforsamling. Torsdag 14. februar 1952.

1) Årsmelding ble lest opp og vedtatt.

Årsmelding for 1951.

Siden forrige generalforsamling er følgende 4 medlemmer avgått ved døden:

Professor M. A. Peacock.
Lektor Adolf Dal.
Bergingeniør S. O. Smith.
Statsgeolog Steinar Foslie.

I samme tidsrom er invalgt følgende 15 nye medlemmer:

338 Thor Siggerud.
339 Fredrik Hagemann.
340 Thane McCulloh.
341 Otto Mellis.
342 P. Michot.
343 Gerd Vogt.
344 J. H. Archer.
345 Finn Skjerlie.
346 Chen Kwan Yuan.
347 Natascha Heintz.
348 Fredrik Huseby.
349 Andre Sandrea.
350 Donald Baker.
351 O. M. B. Bulman.
352 Nils Marklund.

Foreningen har nå 204 medlemmer, herav 2 korresponderende medlemmer, 86 livsvarige medlemmer og 116 årsbetalende medlemmer.

Det er avholdt 7 møter med samlet frammøte av 245 personer.

Av tidsskriftet er utkommet hefte 2—4 av bind 28 og bind 29.

2) Regnskapet ble godkjent.

3) Valg. Resultatene av valget ble:

Formann: *J. A. Dons.*
Viseformann: *L. Størmer.*
Redaktør: *N.-H. Kolderup.*
Sekretær: *N. Spjeldnæs.*

Medlemmer av styret:

G. Henningsmoen, E. Kiil, P. Holmsen og *Th. Vogt* (Trondhjems Geologiske Klubb).

Revisorer: *T. Strand* og *T. Gjelsvik.*
Reuschmedaljekomité: *A. Heintz, Chr. Oftedahl* og *J. A. Dons.*
N. G. F.'s medlemmer av Sulitelmafondets råd for 1952—54:
T. Barth, G. Holmsen, varamann *L. Størmer.*

Utdrag av regnskap for 1951.

Inntekt.

Beholdning, overført fra 1950: I kasse	Kr. 843,23	
I bank	» 9 997,39	
		Kr. 10 840,62
Innbetalt medlemskontingent for 1947	Kr. 15,00	
—»— —»— » 1948	» 105,00	
—»— —»— » 1949	» 135,00	
—»— —»— » 1950	» 900,00	
—»— —»— » 1951	» 990,00	
		» 2 145,00
Tilskudd fra staten		» 1 200,00
Tilskudd fra Norges Almenvitenskapelige Forskningsråd		» 9 845,78
Abonnement og salg av tidsskriftet		» 2 493,50
Renter av bankinnskudd		» 173,89
Renter fra livsvarige medlemmers fond		» 346,77
Renter fra Berg- og steinindustriens fond		» 407,62
		Kr. 27 453,18

Utgift.

Tidsskriftet: Trykning, Bind 28, h. 2—4	Kr. 7 744,48	
Klisjeer, —»—	» 2 101,30	
		Kr. 9 845,78
Arbeidshjelp, porto og skrivesaker		» 898,05
Møter og ekskursjoner		» 346,03
Rabatt ved salg av tidsskriftet		» 579,47
Representasjon og Reuschmedaljen		» 353,60
Beholdning, overført til 1952: I kasse	Kr. 644,44	
I bank	» 14 785,81	
		» 15 430,25
		Kr. 27 453,18

Livsvarige medlemmers fond.

		Inntekt	Utgift
1951 1. jan. Fondets kapital:			
Obligasjoner	Kr. 500,00		
Bankinnskudd	» 11 250,00		
Innbetalt kontingent i 1951	» 800,00		
Urørlig kapital	Kr. 12 550,00		
Renter av obligasjoner og bankinnskudd		Kr. 352,77	
Forvaltning av verdipapirer			Kr. 6,00
Overført renter til ordinære budsjett			» 346,77
		Kr. 352,77	Kr. 352,77

Berg- og steinindustriens gavefond.

		Inntekt	Utgift
1951 1. jan. Fondets kapital:			
Urørlig	Kr. 20 000,00		
Disponibel	» 5 554,00		
Renter for 1951		Kr. 407,62	
Overført renter til ordinære budsjett			Kr. 407,62
		Kr. 407,62	Kr. 407,62

Regnskapet revidert av T. Strand og T. Gjelsvik, Oslo, 11. jan. 1952.

Møte 337. Torsdag 14. februar 1952.

Innvalg:

(353) *Kautsky, Gunnar,* fil. lic., S. G. U., Stockholm 50, Sverige, foreslått av G. Henningsmoen og S. Skjeseth.

(354) *Ljunggren, Pontus,* fil. lic., Geol. Inst. C. T. H., Gibraltarsgatan 5 a, Göteborg, Sverige, foreslått av G. Henningsmoen og N. Spjeldnæs.

(355) *Sørensen, Henning,* mag. scient., Geologisk museum, Oslo 45, foreslått av G. Henningsmoen og N. Spjeldnæs.

1) Direktør *C. Bugge* holdt minnetale over statsgeolog Steinar Foslie.

2) Statsgeolog *Per Holmsen* holdt kåseri fra Alpeekskursjonene i anledning 25-års jubileet for Mineralogisk-Petrografisk Selskap i Sveits 1950. (Med lysbilder.)

NORSK GEOLOGISK FORENING

MEDLEMSLISTE

à jour juli 1952.
^{1}: korresponderende medlem.
*: livsvarig medlem.
Tallet i parentes er innvalgsåret.
(S): stifter (18. februar 1905).

*Adamson, Olge J., dr. Cort Adelers gate 12, vær. 710, Oslo. (1945).
Ahlmann, Hans W:son, ambassadør. Svenske ambassade, Meltzer's gate 4, Oslo. (1919).
Alsgaard, P., overingeniør. Herøya pr. Porsgrunn. (1945).
Andersen, S. A., dr. Studiestrædet 3^4, København. (1947).
^{1}Archer, J. H., lektor. Åsen terrasse 2 B, Horten. (1951).
Asklund, Bror, statsgeolog. Sveriges Geologiska Undersökning, Stockholm 50. (1938).
*Bache, Laura, lektor. Nordengvegen 14, Røa, Oslo. (1931).
*Backlund, Helge, professor. Mineralogisk-geologiska Institutionen, Uppsala 1. (1919).
Baker, Donald, B. Sc. Dept. of Geology, Princeton University, Princeton, N. J., U. S. A. (1951).
*Balk, Robert, professor. Dept. of Geology, University of Chicago, Chicago 37, Ill., U. S. A. (1933).
*Barth, Tom. F. W., professor. Geologisk museum, Oslo 45. (1921).
Bergersen, Birger, ambassadør. Norske ambassade, Strandvägen 113, Stockholm. (1921).
Bertheau-Hansen, Chr., bergingeniør. Norges geologiske undersøkelse, Oslo 27. (1942).
Birkeland, Tor, lektor. Avaldsnesgt. 36, Stavanger. (1946).
Bjerrum, Lauritz, ingeniør. Geoteknisk institutt, Blindern, Oslo. (1952).
*Bjørlykke, Harald, dr. Norsk Bergverk, Christian August's gate 15, Oslo. (1923).
Boughton, Eric. Hay Tor, 921 Harrow Rd., Wembley, Middlesex, England. (1932).
*Broch, Olaf Anton, professor. Dept. of Mineralogy, University of Punjab, Lahore, Pakistan. (1920).
Bruun, B., ingeniør. Geologisk museum, Oslo 45. (1938).
*Braastad, Johan, dr. Postboks 808, Oslo. (1913).
Bugge, Arne, dr. Utsiktsveien 21, Stabekk. (1914).
*Bugge, Carl, dr. Håkon den gode's vei 12, Vindern, Oslo. (S).
*Bugge, Jens, dosent. Norges tekniske høgskole, Trondheim. (1940).
*Bulman, O. M. B., dr. Sedgwick Museum, Cambridge, England. (1951).
*Callisen, Karen, dr. Mineralogisk og Geologisk Museum, Østervoldgade 7, København K. (1917).
Carlson, Fredrik, overingenior. Sandelsgatan 35^5, Stockholm. (1919).
*Carstens, Harald, cand. real. Fosdalens Bergverks-A/S, Malm. (1949).
*Chapman, Charleton A., professor. University of Illinois, Urbana, Ill., U. S. A. (1949).
*Chen Kwan Yuan, B. Sc. Geological Institute, National Peking University, Peking, Kina. (1951).

Collini, Bengt, fil. lic. Mineralogisk-geologiska Institutionen, Uppsala, Sverige. (1949).
Craig, H. B., M. A. Dept. of Geology, University, Chicago 37, Ill., U. S. A. (1949).
*Dahl, Eilif, cand. real. Botanisk institutt, Blindern, Oslo. (1946).
Dahl, Erling, ingeniør. Skogveien 1, Notodden. (1945).
Dahlström, Elis, fil. lic. Birger Jarlsgatan 81, Stockholm. (1945).
Danielsen, Anders, konservator. Botanisk museum, Universitetet, Bergen. (1949).
*Danielsen, D. A., rektor. Hornnes, Setesdal. (1905).
*Devore, W. George, M. A. Dept. of Geology, University, Chicago 37, Ill., U. S. A. (1948).
Dietrichson, Brynjulf, bergingeniør. Hvitstein. (1917).
Donnay, J. D. H., professor. John Hopkins University, Baltimore 18, Maryland, U. S. A. (1937).
Dons, Johannes A., konservator. Slyngveien 14, Smestad, Oslo. (1941).
*Eckermann, Harry von, professor. Edeby pr. Sparreholm, Sverige. (1937).
Egeberg, F. P., bergingeniør. Rådhusgata 5 b, Oslo. (1939).
Enkovaara, Antti, magister. Oulainen, Finnland. (1947).
Eriksen, Edv. Andreas, bergingeniør. Uranienborgveien 11 c, Oslo. (1945).
*Eskola, Pentti, professor. Min. Inst., Universitetet, Helsingfors. (1919).
Espeland, Margaret, B. Sc. Vei 3672, Nordstrandshøgda, Oslo. (1950).
*Falkenberg, Otto, ingeniør. Priorveien 7, Smestad, Oslo. (1914).
Feyling-Hanssen, Rolf, univ.-stip. Geologisk museum, Oslo 45. (1950).
*Fægri, Knut, professor. Universitetet i Bergen. (1935).
Færden, Johannes, statsgeolog. Norges geologiske undersøkelse, Oslo 27. (1948).
*Føyn, Sven, direktør. Norges geologiske undersøkelse, Oslo 27. (1932).
Garthus, Torbjørn, lærar. Garthus, Valdres. (1943).
*Gjelsvik, Tore, statsgeolog. Evjebakken 18, Sandvika. (1945).
Gjessing, Leiv, læge. Dikemark sykehus, Asker. (1945).
*Gleditsch, Chr., cand. real. Boks 18, Skøyen, Oslo. (1941).
Grenness, Johanness, ingeniør. Statens Råstofflaboratorium, Østmarka, Trondheim. (1945).
*Grip, Erland, fil. lic. Boliden, Sverige. (1938).
*Grønlie, Arne, lektor. Orkdal landsgymnas, Orkanger. (1943).
*Grønlie, O. T., rektor. Heimdal st., Sør-Trøndelag. (1909).
Hagemann, Fredrik, stud. real. Hjelmsgt. 6 A, Oslo. (1951).
*Hagner, A. F., professor. University of Illinois, Urbana, Ill., U. S. A. (1947).
Hansen, Kaj, dr. Gammeltoftsgade 16, København K. (1947).
*Harry, W. T., B. Sc. University College, Dundee, Scotland. (1949).
*Hartley, Jack, B. Sc. Department of Geology, University, Leeds 2, England. (1949).
*Hawkes, Leonard, geologist. Bedford College, Regents Park, London N.W. 1. (1915).
*Heber, Gustav, advokat. Oscarsgt. 49, Oslo. (1938).
*Heber, Gustav, bygningsingeniør. Oscarsgt. 46 b, Oslo. (1942).
*Heintz, Anatol, professor. Geologisk museum, Oslo 45. (1926).
Heintz, Natascha, stud. real. Presteveien 84, Blommenholm. (1951).
Heltzen, Anders M., hyttemester. Kongsberg Sølvverk. (1941).
*Helverschou, Kaare, disponent. Villavegen 9, Frøen, Oslo. (1943).
*Henderson, Donald M., dr. University of Illinois, Urbana, Ill., U. S. A. (1949).
*Henningsmoen, G., konservator. Geologisk museum, Oslo 45. (1941).
Hernes, Ivar, cand. real. Geologisk institutt, N. T. H., Trondheim. (1947).
*Hesse, P. A. Jürgen, bergingeniør. Nynäsvägen 304, Enskede, Stockholm, Sverige. (1936).
Hessland, Ivar, dosent. Paleontologiska Institutionen, Uppsala 5. (1947).

Higazy, R., dr. Grant Institute of Geology, West Mains Road, University, Edinburgh, Scotland. (1947).
Hjelmqvist, Sven, professor. Geologiska Inst., Lund, Sverige. (1949).
Hofseth, Arne, bergingeniør. Orkla Gruber, Løkken Verk. (1952).
*Holmsen, Andreas, bergmester. Bestun, Ullern. (S).
Holmsen, Bjarne, direktør. Kjøpsvik. (1941).
*Holmsen, Gunnar, dr. Skådalen, Oslo. (1908).
*Holmsen, Per, statsgeolog. Norges geologiske undersøkelse, Oslo 27. (1940).
Holtedahl, Hans, konservator. Geologisk institutt, Universitetet i Bergen. (1948).
*Holtedahl, Olaf, professor. Geologisk institutt, Blindern, Oslo. (1908).
Huseby, Fredrik, cand. real. Norsk Bergverk, Chr. Augustsgt. 15, Oslo. (1951)
*Høeg, Ove Arbo, professor. Farmasøytisk institutt, Blindern, Oslo. (1924).
Høegh-Omdal, S. K., byråsjef. Utgarveien 12, Jar pr. Oslo. (1945).
*Isachsen, Fridtjov, professor. Geografisk institutt, Blindern, Oslo. (1929).
*Jakhelln, Johanne Hødal, cand. real. United Nations, Box 20, Gr. Central P. O., New York 17, N. Y., U. S. A. (1943).
Jensen, Einar, dr. Villavegen 24 b, Rjukan. (1939).
Johnson Høst, Mimi, læge. Lillestrøm. (1913).
Kautsky, Gunnar, fil. lic. Sveriges Geologiska Undersökning, Stockholm 50, Sverige. (1952).
*Kennedy, W. Q., D. Sc., F. R. S, professor. University of Leeds, Leeds 2, England. (1947).
*Kiil, Erling, bergingeniør, Branteborgveien 2, Slemdal, Oslo. (1922).
*Klompé, Theo., professor. University of Indonesia, Geological Section, Dj, Ganeca 10, Bandoeng, Java, Indonesia. (1947).
Klüver, Emil, ingeniør. Statens toll-laboratorium, Oslo. (1926).
Knorring, Oleg von, fil. lic. Department of Geology, University, Leeds 2, England. (1949).
*Kolderup, Niels-Henr., professor. Universitetet i Bergen. (1919).
*Kollerud, Martha, cand. mag. Trondheimsvegen 10, Oslo. (1929).
*Kristoffersen, K., dr. A/S Norsk Jernverk, Nedre Volgate 8, Oslo. (1941).
*Kullerud, Gunnar, ingeniør. Geologisk museum, Oslo 45. (1948).
Kvale, Anders, dosent. Geologisk institutt, Universitetet i Bergen. (1936).
Kvalheim, Aslak, ingeniør. Statens Råstofflaboratorium, Østmarka, Trondheim. (1944).
Landergren, Sture, dosent, laborator. Stockholm 50. (1943).
Landmark, Einar, direktør. Rådhusgt. 5 b, Oslo. (1941).
Landmark, Kåre, konservator. Tromsø museum, Tromsø. (1943).
*Larsson, Tollef, cand. real. Engene Fabrikker, Sætre i Hurum. (1945).
Laursen, Dan, lektor. Julius vej 6, Gentofte, København. (1947).
*Lenander, N. E., direktør. Nordlandsgatan 7—9, Stockholm. (1914).
Liestøl, Olav, glasiolog. Norsk Polarinstitutt,Observatoriegt. 1, Oslo. (1947).
*Lindley, Henry W., dr. Die techn. Hochschule, Wullner Str. 2, Aachen, Tyskland. (1928).
Ljunggren, Pontus, fil. lic. Geologiska Institutionen, C. T. H., Gibraltarsgatan 5 A, Göteborg, Sverige. (1952).
Lund, Kjell, direktør. A/S Sulitjelma Gruber, Fr. Nansens pl. 6, Oslo. (1938).
*Lund, Lars, mag. sc. Forsvarets Forskningsinstitutt, Kjeller pr. Lillestrøm. (1943).
Lund, Worm Hirsch, direktør. Jacob Fayes veg 2, Bygdøy, Oslo. (1941).
Lund, Worm, bergingeniør. A/S Sydvaranger, Kongensgt. 5, Oslo. (1941).
*Lundby, Sven Erik, arkitekt. Kontoret for byggforskning, Blindern, Oslo. (1937).
Løddesøl, Åsulv, direktør. Det norske myrselskap, Rosenkrantzgt. 8, Oslo. (1938).
Løvaas, Gunnar, bergingeniør. Skorovas Gruber, Trangfoss st. (1949).

*Låg, J., professor. Norges Landbrukshøgskole, Vollebekk. (1943).
Magnusson, N. H., professor. Vallhallavägen 46, Stockholm. (1937).
*Major, Harald, geolog. Norsk Polarinstitutt, Observatoriegt. 1, Oslo. (1944).
Major, Robert, direktør. Norges Tekn.-Naturv. Forskningsråd, Jernbanetorget 2, Oslo. (1941).
Marklund, Nils, fil. lic. Gruvförvaltningen, Boliden, Sverige. (1951).
*Marmo, Vladi, magister Mineralogisk Institutt, Universitetet, Helsingfors. (1949).
*Marstrander, Henning, bergingeniør. 2924 Leland Road, Homewood, Birmingham 9, Alabama, U. S. A. (1917).
*Marthinussen, Marius, lektor. Ski kom. h. almenskole, Ski. (1931).
McCulloh, Thane H., M. S. 960 10th Street, Santa Monica, Calif., U. S. A. (1951).
Mellis, Otto, dr. Min. Inst., Stockholms Högskola, Stockholm. (1951).
Meyer, S. Smith, direktør, Stordø gruber. (1924).
[1] Michot, Paul, professor. Inst. de Géologie, Université de Liége, Liége, Belgia. (1951).
Monsen, Astrid, cand. real. Nyhaugsveien 10, Minde pr. Bergen. (1935).
Mortensen, Odd, cand. real. Postboks 519, Bergen. (1938).
Mortenson, Magne, dosent. Norges tekniske høgskole, Trondheim. (1948).
Munck, Sole, museumsinspektør. Mineralogisk og Geologisk Museum, Østervoldgade 7, København K. (1948).
*Neumann, H., førstekonservator. Geologisk museum, Oslo 45. (1940).
Newhouse, W. H., professor. Dept. of Geology, Chicago 37, Ill., U. S. A. (1947).
*Noe-Nygaard, Arne, professor. Østervoldgade 7, København K. (1934).
Norem, Olav, overingeniør. Heistad st., Eidanger. (1945).
Norin, Erik, professor. Mineralogisk-geologiska Institutionen, Uppsala 1. (1947).
*Nørregaard, E. M., cand. mag. Mineralogisk og Geologisk Museum, Østervoldgade 7, København K. (1917).
*Oftedahl, Christoffer, statsgeolog. Postboks 256, Stabekk. (1941).
*Oftedal, Ivar, professor. Mineralogisk institutt, Blindern, Oslo. (1918).
*Orvin, A. K., bergingeniør. Håkon den godes vei 21, Vindern, Oslo. (1913).
Ottesen, P. O., lensmann. Manger pr. Bergen. (1915).
Paulsen, Nils, bergingeniør Berg, Maridalen, Oslo. (1947).
*Pettersson, Adam, bergingeniør. Lysaker ved Oslo. (1918).
*Poulsen, Arthur O., statsgeolog. Norges geologiske undersøkelse, Oslo 27 (1941).
*Quensel, Percy, professor. Stockholms Högskola, Stockholm. (1916).
Ramberg, Hans, professor. Dept. of Geology, Univ. of Chicago, Chicago, Ill., U. S. A. (1941).
Ramsli, Gunnar, cand. mag. Munkerudåsen 24 c, Nordstrandshøgda, Oslo. (1948).
Rankama, Kalervo, professor. Geologisk institutt, Universitetet, Helsingfors. (1947).
Regnéll, Gerhard, dr. Geologisk-paleontologiska Inst., Lund, Sverige. (1947).
*Rosendahl, Halvor, konservator. Geologisk museum, Oslo 45. (1918).
*Rosenlund, A. L., jernbanegeolog. Drammensveien 103, Oslo. (1912).
Rosenqvist, Annemor, amanuensis. Kjemisk institutt, Blindern, Oslo. (1946).
Rosenqvist, Ivan Th., dr. Geoteknisk institutt, Blindern, Oslo. (1941).
Ross, Harald N., direktør. Kongsberg Sølvverk, Kongsberg. (1947).
Rutherford, G. K., M. Sc. Norges Landbrukshøgskole, Vollebekk. (1952).
*Rønning, O., ingeniør. Skorovas Gruber, Trangfoss st. (1938).
Samuelsen, Andreas, lektor. Landåsveien 8c, Bergen. (1929).
Sandrea, André, Ph., professor. Laboratoire de Minéralogie, Musée Nation. Hist. Natur. Paris V. (1951).

*Scheumann, K. H., professor. Universität Bonn, Nussalleè 2, Bonn a. Rhein, Tyskland (1928).
Selmer-Olsen, Rolf S., statsgeolog. Norges geologiske undersøkelse, Oslo 27. (1948).
Semb, Gunnar, forsøksleder. Norges Landbrukshøgskole, Vollebekk. (1941).
Siggerud, Thor, cand. mag. Mineralogisk institutt, Blindern, Oslo. (1951)
Skjerlie, Finn, stud. mag. scient. Roald Amundsens vei 97, Bergen. (1951).
Skjeseth, Steinar, statsgeolog. Geologisk museum, Oslo 45. (1949).
Skordal, Asbjørn, geolog. »Vestråt«, Elvegaten 18, Trondheim. (1946).
Smaadal, Gerd Vogt, cand. real. Gyssestadkollen 25, Slependen. (1951).
Smith, H. H., bergingeniør. Drachmannsgatan 2, Bromma, Stockholm. (1926).
*Sobral, José M., dr. Avenida de los incas 3020, Buenos Aires. (1931).
Soot-Ryen, T., direktør. Tromsø museum, Tromsø. (1946).
Spjeldnæs, Nils, cand. real. Geologisk museum, Oslo 45. (1946).
*Steinsvoll, Søren, overgartner. Botanisk hage, Trondheimsvn. 23, Oslo. (1942).
Stenvik, Kr., bestyrer. Statens Olivinmølle A/S, Åheim, Sunnmør. (1936).
Storebakken, H. C., cand. real. »Sætra«, Svelvik, Vestfold. (1940).
*Strand, Trygve, statsgeolog. Norges geologiske undersøkelse, Oslo 27. (1927).
Streitlien, Ivar, fylkesskulelerar. Tynset. (1943).
*Strøm, Kaare, professor. Limnologisk institutt, Blindern, Oslo. (1932).
Støren, R., bergingeniør. Kongsberg. (1915).
*Størmer, Leif, professor. Geologisk museum, Oslo 45. (1925).
Sund, Tore, dr. philos. Norges handelhøgskole, Bergen. (1943).
Sunde, Albert C., bergingeniør. Oscarsgt. 46, Oslo. (1948).
*Sverre, Erik, jr., disponent. Postboks 15, Skøyen st., Oslo. (1946).
Sæther, Egil, amanuensis. Geologisk institutt, N. T. H., Trondheim. (1943).
*Sørbye, Ruth C., cand. real. Universitetet i Bergen. (1941).
Sørensen, Henning, mag. scient. Geologisk museum, Oslo 45. (1952).
Thorslund, Per, professor. Paleontologiska Institutionen, Uppsala. (1950).
*Trøften, Einar, bergingeniør. Sulitjelma. (1921).
*Undås, Isak, lektor. Fløienbakken 8 b, Bergen. (1931).
*Vogt, Thorolf, professor. Norges tekniske høgskole. Trondheim. (1908).
Wager, L. R., professor. The University Museum, Oxford, England. (1949).
Watnelie, G. A., lektor. Vatneli p. å., Aust-Agder. (1913).
[1] Wegmann, C. E., direktør. Fbg. de l'hôpital 43, Neuchâtel, Schweiz. (1925).
Werenskiold, Werner, professor. Geografisk institutt, Blindern, Oslo. (1909).
*Wickman, Frans E., professor. Riksmuseet, Stockholm 50. (1945).
Winsnes, Thore, geolog. Abbedikollen 34, Ullern. (1947).
Wolff, Francis, lektor. Idrettsveien 1, Bergen. (1945).
Wærn, Bertil, fil. lic. Paleontologiska Institutionen, Uppsala 5. (1947).
Zachariasen, William, professor. Ryerson Physical Laboratory, Chicago, Ill., U. S. A. (1929).
*Øien, Fritz, bergingeniør. Statens Teknologiske Institutt, Akersveien 24 c, Oslo. (1945).
Ørvig, Tor, dr. Paleozoologiska Avd., Riksmuseet, Stockholm 50. (1941).
Øverlie, Olav, bergingeniør. Rødsand gruber, Rausand om Molde. (1949).
*Ånerud, Kåre, lektor. Mossevegen 220, Nordstrand, Oslo. (1931).
Aasgaard, Gunnar, bergmester. Elgesetergt. 51^3, Trondheim. (1921).

2 korresponderende medlemmer
89 livsvarige medlemmer.
116 årsbetalende medlemmer.

207 medlemmer.